Selecting a Map Projection

GEOG482 Spring 2020

- *“…there is no such thing as a bad projection – there are only good and bad choices.”*

Arthur Robinson

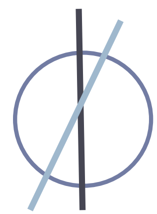
The round earth vs. a flat map

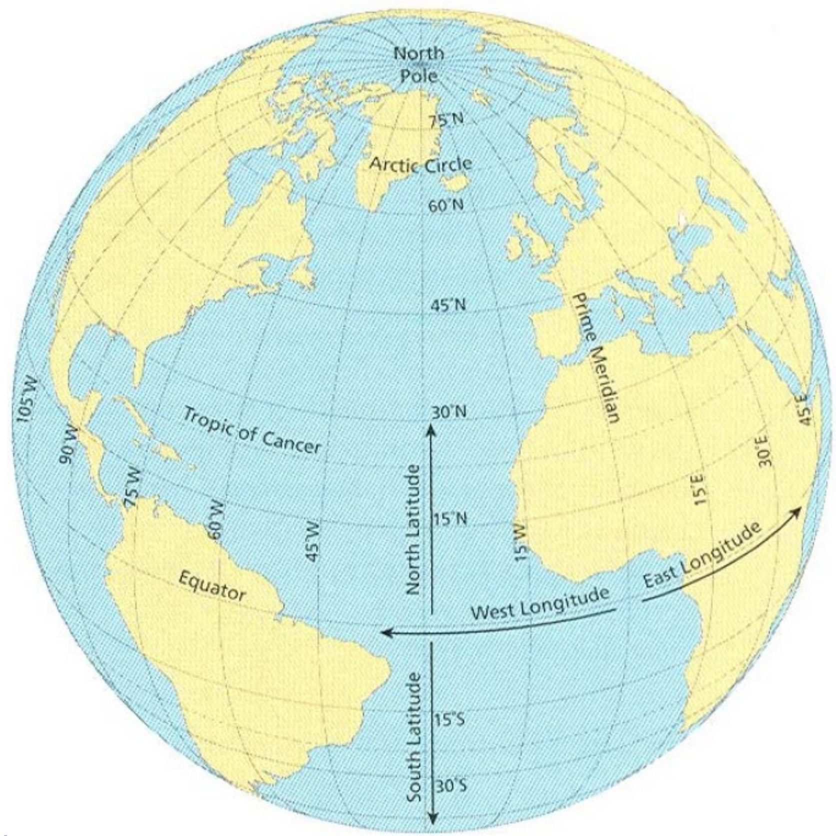
- The process of map projections
- Geographic coordinates
- Projected coordinates
- Map projection characteristics
- Distortion
- Scale and scale factor
- Projection selection
- More projection examples

(image sources: http://www.art-head-start.com/free-3d-models.html, maps.google.com)

The spherical Earth

- Points of reference based on Earth's position relative to the sun…
  - Equator
  - North and south poles
    - Cf. Magnetic poles
- …and arbitrary agreements
  - Prime meridian
- Reference system
  - A geographic grid (graticule) measured in a *sexagesimal (base-sixty) scale; degrees, minutes,* and seconds





View of earth centered on 30° N, 30° W

Source: Goode's World Atlas

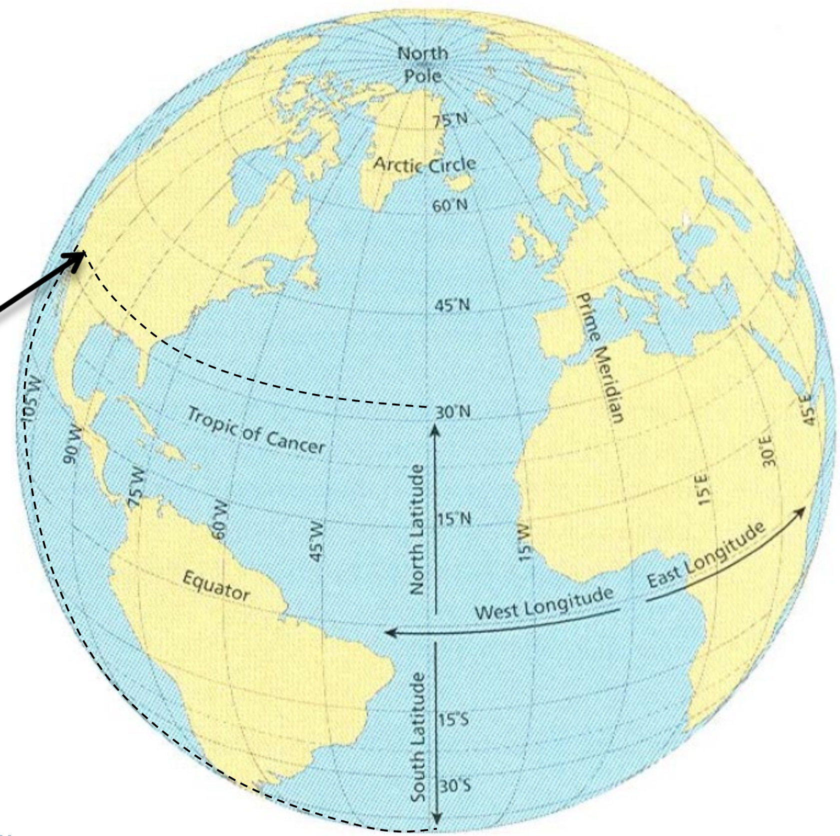
The spherical Earth – the geographic grid

- Lines of longitude – Meridians (|)
  - From pole to pole
  - E and W of the Prime meridian

- Lines of latitude – Parallels (—)
  - East ←→ West
  - N and S of the Equator

- E.g., 1250 N Bellflower Blvd
  Long Beach, CA 90840

	Decimal Degrees	Deg:Min:Sec
Lat:	33.781466	33° 46' 53.28" N
Lon:	-118.119035	118°7' 8.53" W



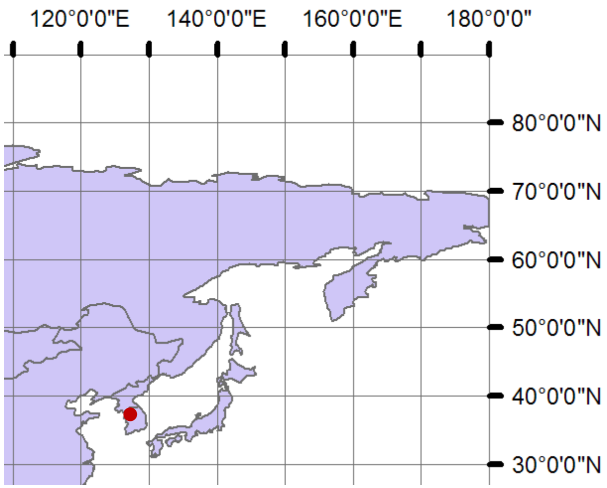
View of earth centered on 30° N, 30° W

Source: Goode's World Atlas

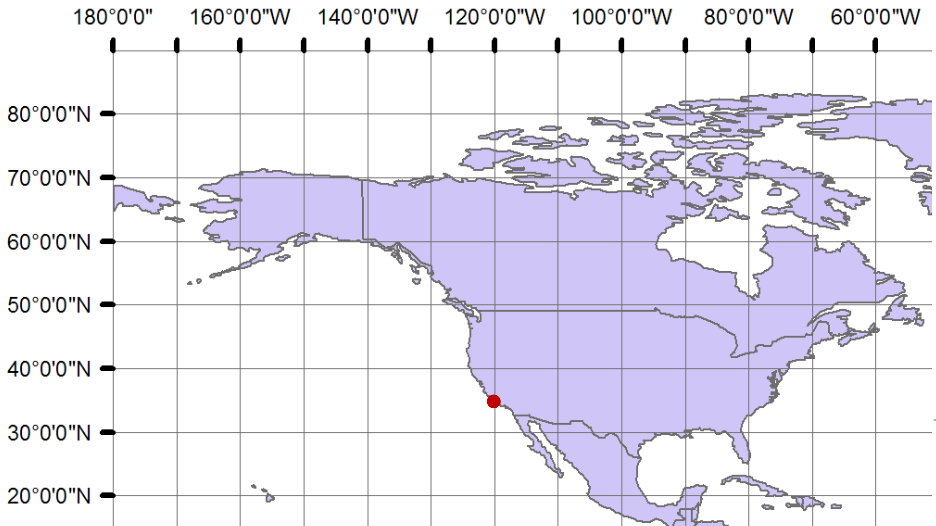
Some examples

- Where is Seoul, Korea?

Lat. 37° 34' N
Long. 126° 58' E



- What's at
  - Lat. 33° 49' N
  - Long. 118° 9' W ?



Long Beach, CA

Converting from DMS to DD

- To convert degrees, minutes, and seconds (DMS) to degrees and decimals of a degree (DD): ex) **59°19′ 48″ N**

1. Convert the seconds

Since there are 60 seconds in each minute,
59°19′ $\boxed{48'' / 60}$ converts to 59°19$\boxed{.8}$′

2. Convert the minutes

Since there are 60 minutes in each degree
59°$\boxed{19.8' / 60}$ converts to **Lat. 59$\boxed{.33}$ °**

Calculator example: 18° 04′12″ E

Enter 12.00 / 60 = then displays 0.2

Enter + 4 = then displays 4.2

Enter / 60 = then displays 0.07

Enter + 18 = then displays 18.07

Long. 18.07 is your final decimal degrees for longitude

3. For South or West Coordinates, add a negative sign to the DD

Converting from DD to DMS

- To convert degrees, minutes, and seconds (DMS) from degrees and decimals of a degree (DD): ex) **Lat. 59.33**

1. The whole number part is the whole degrees, 59 °.
2. Subtract the whole degrees (59.33 – 59 = 0.33) and multiply the decimal degree to minutes. 0.33 * 60 = 19.8 (the number of minutes in a degree).
   The whole number of the answer is the whole minutes, 19 ′.
3. Subtract the whole minutes from the answer (19.8 – 19 = 0.8) and multiply the decimal minutes to seconds. 0.8 * 60 = 48 (the number of seconds in a minute).
   The answer is the seconds, 48 ″.
4. If there is a decimal remaining, keep as the decimal of a second.

   Answer: 59° 19′ 48″ N

Exercise

Convert from DD to DMS: Long. -18.07

Some things to note

- On a spherical grid:
  - Scale is the same everywhere on the globe
  - Meridians (|) are spaced evenly on parallels and converge towards the poles
  - Parallels (—) are parallel… and spaced equally on the meridians
  - Meridians and parallels intersect at right (90°) angles
  - Quadrilaterals of a certain longitudinal extent have equal areas
  - Areas of quadrilaterals decrease towards the poles

Terms related to distance and direction

- Great Circle
  - Formed by plane cutting through the center of the Earth and its intersection with the surface
  - E.g., Equator, meridians – measure shortest distance from a Great Circle (themselves)
    - All great circles have equal lengths
- Small circle
  - E.g., Parallels

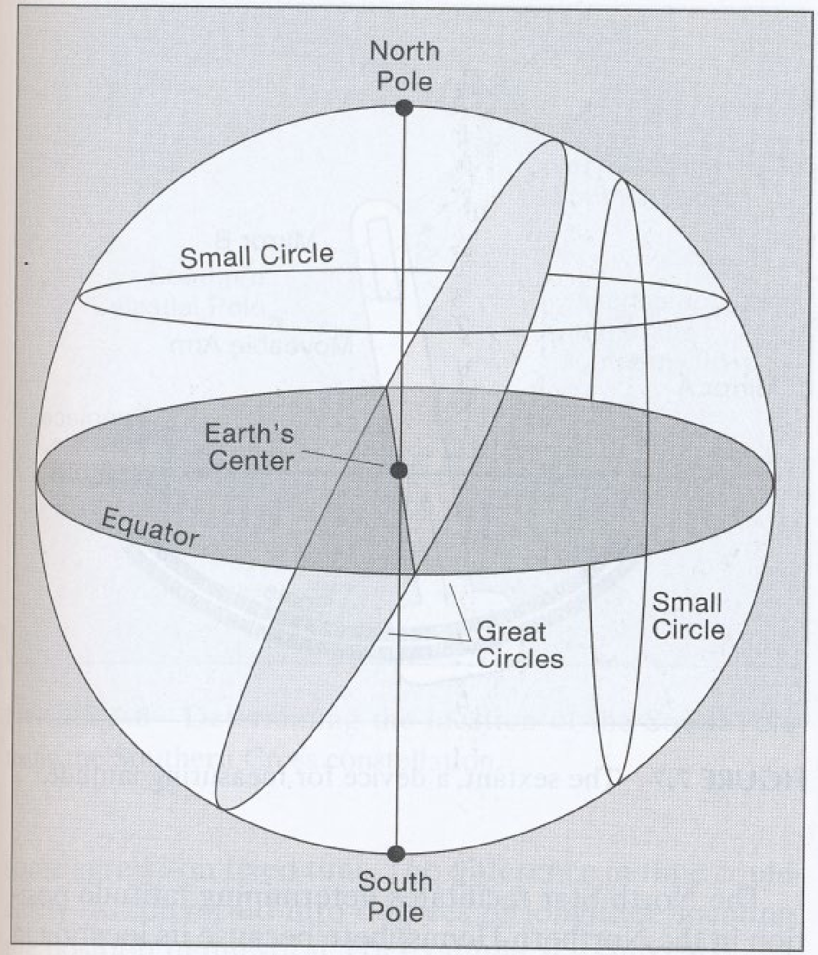


FIGURE 7.4 Examples of great and small circles on the Earth's surface.

(Source: Slocum et al. 2009)

Terms related to distance and direction (cont.)

- Azimuth
  - Measures angles between meridians from points A to B
    - E.g., a, b, and c in the figure 7.5
  - Useful for describing direction of the shortest path (on a great circle) between two points
    - E.g., points A and B

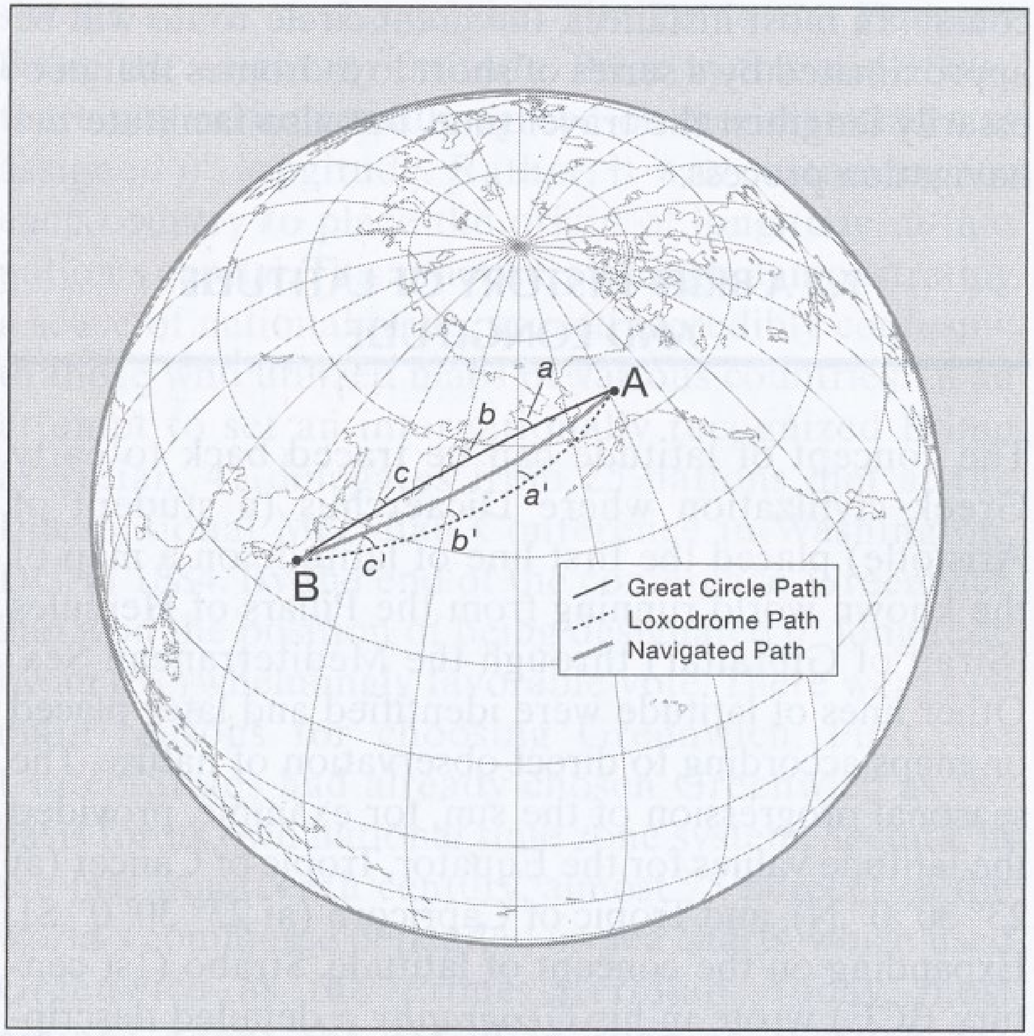
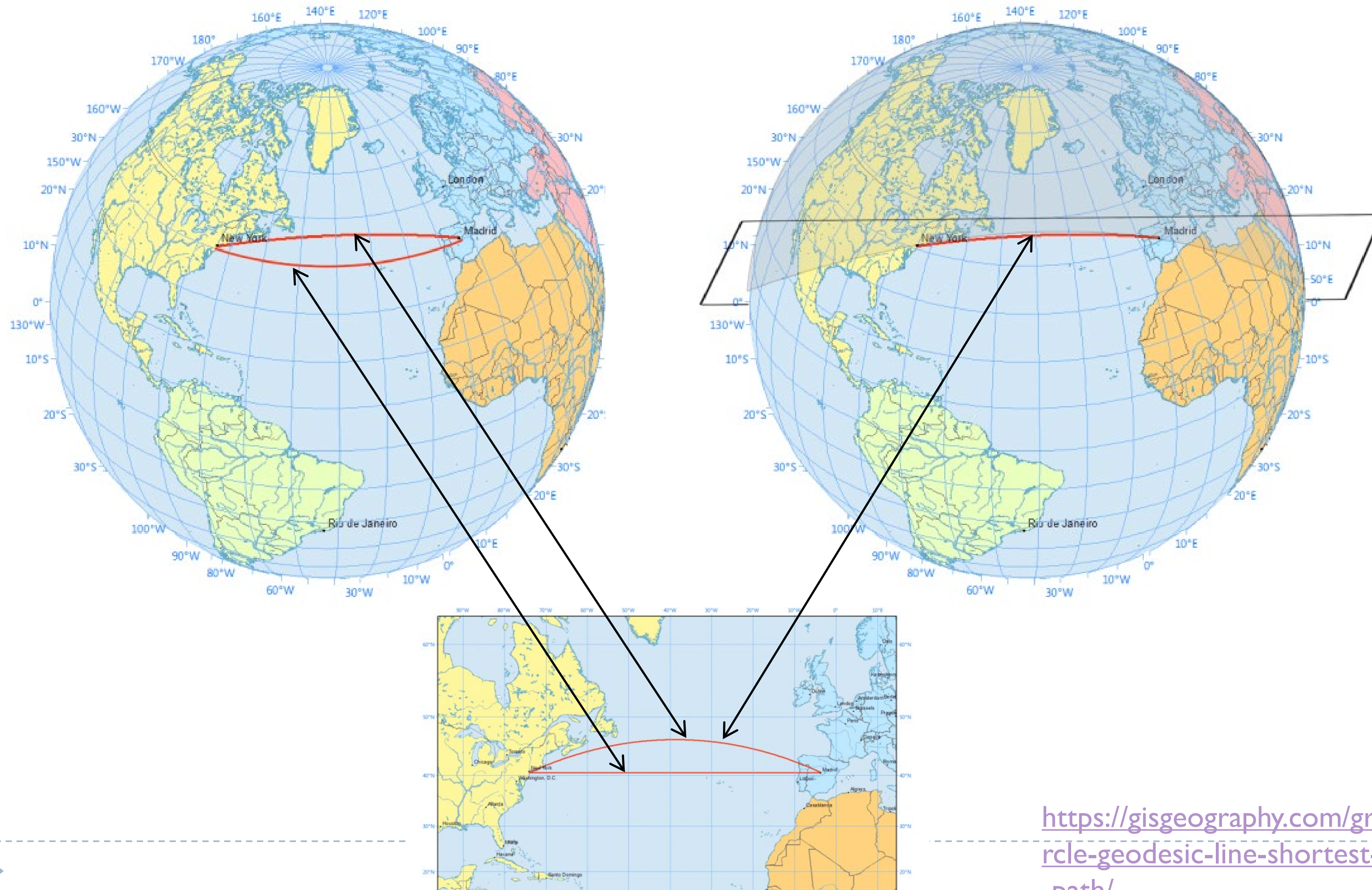


FIGURE 7.5 A great circle arc from point A to point B

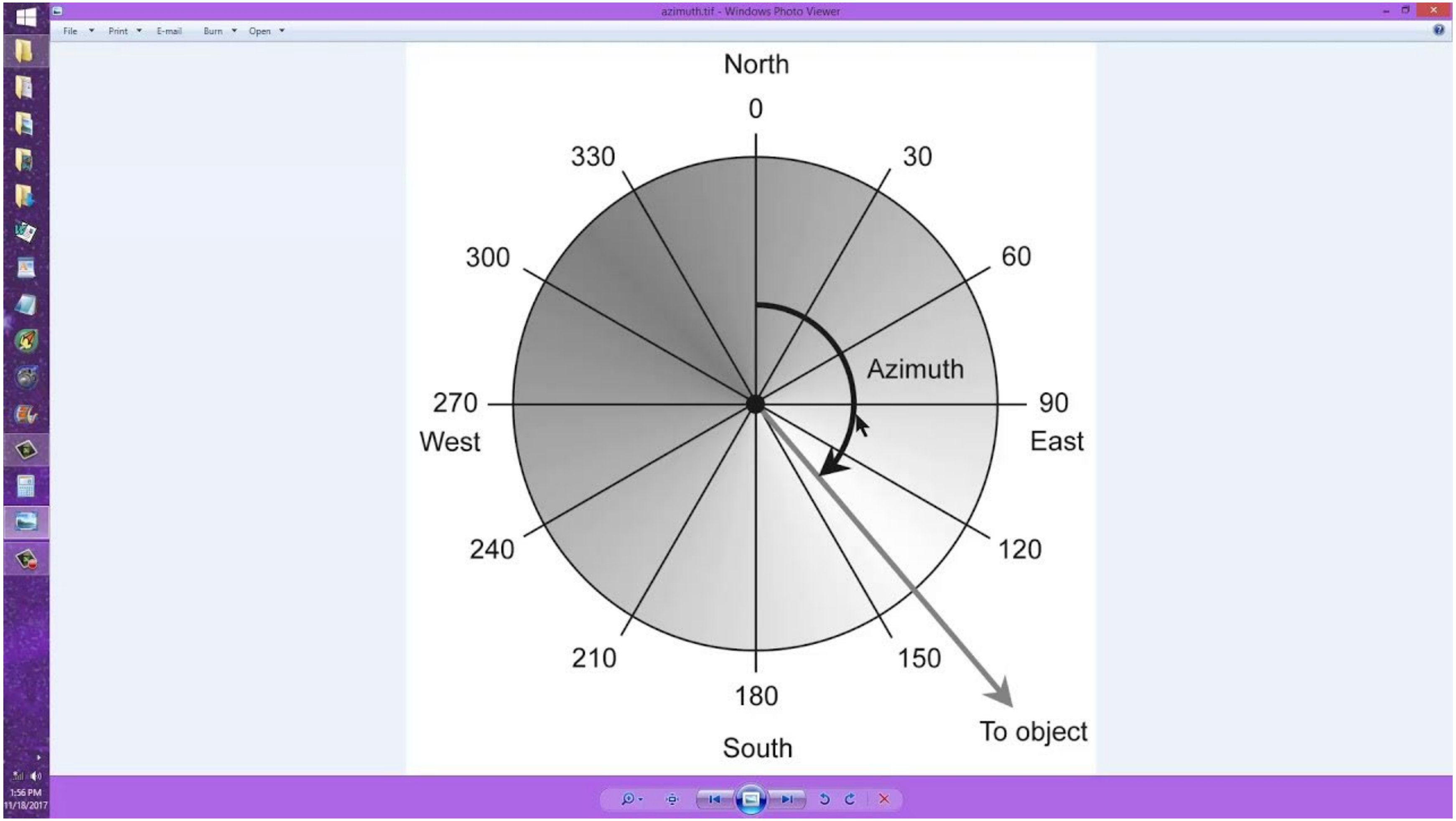
(Source: Slocum et al. 2009)

Great circle path



https://gisgeography.com/great-circle-geodesic-line-shortest-flight-path/

Azimuth (cont.)



- [Source: https://www.youtube.com/watch?v=g1iDIX7R6Vo](https://www.youtube.com/watch?v=g1iDIX7R6Vo)

Terms related to distance and direction (cont.)

- Loxodrome
  - A path formed by keeping a constant bearing from points A to B
  - Useful for navigation

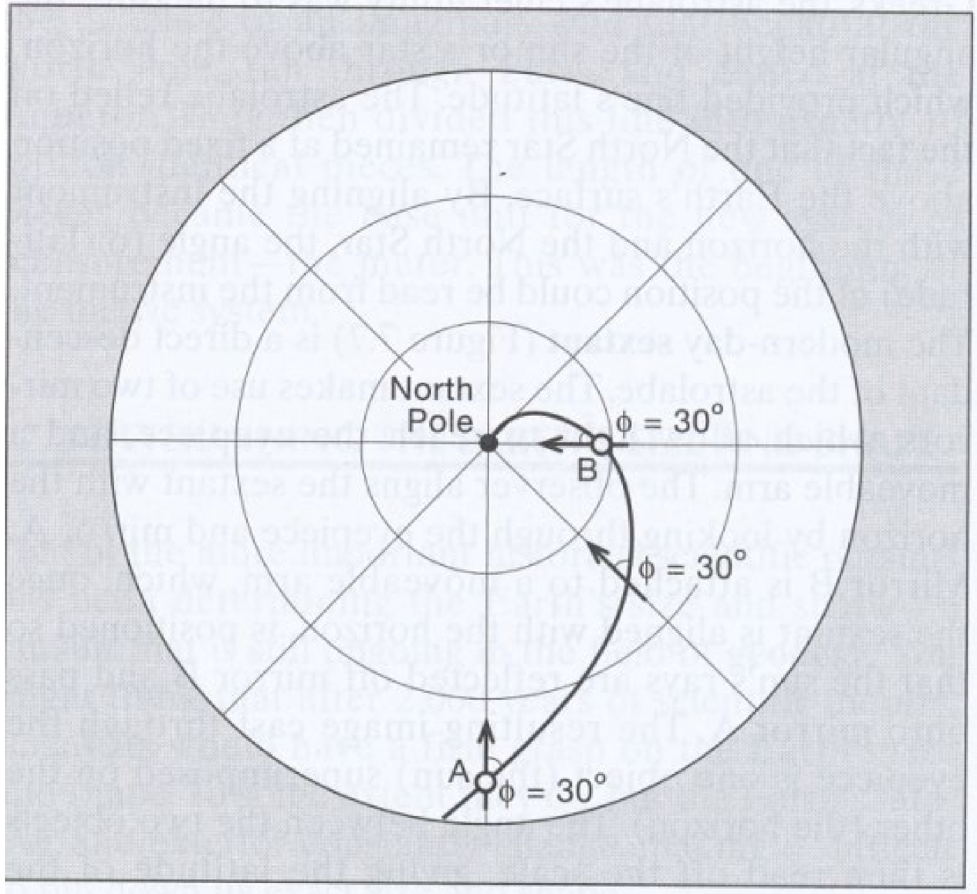
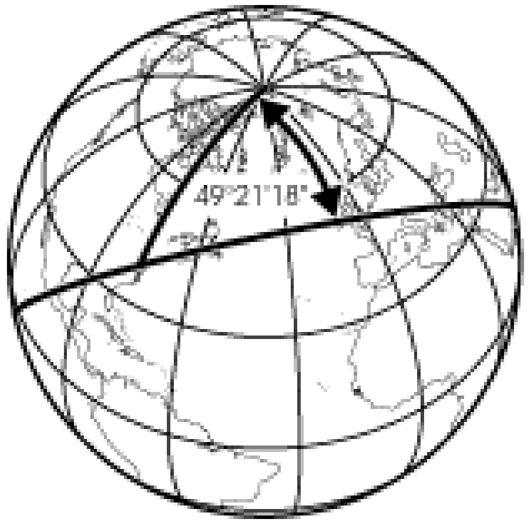


FIGURE 7.6 A line drawn from point A to point B crossing each meridian at a constant angle is called a loxodrome. If extended, this line will continue to spiral toward the North Pole.

(Source: Slocum et al. 2009)

Azimuth vs. Loxodrome



Great circle route through
Washington, D.C., and London.
Azimuth of 49°21'18" from D.C.

Loxodromic route through
Washington, D.C. and London.
Bearing of 76°48'26"

https://www.mapthematics.com/Essentials.php

The Earth is not precisely round

- Earth's rotation and differences in geology/density results in a non-spherical shape
- Geodesy refers to Earth's true shape as the geoid
  - Average ocean surface of the Earth
- To calculate locations easier a reference ellipsoid is used that approximates the geoid
- This introduces some distortions

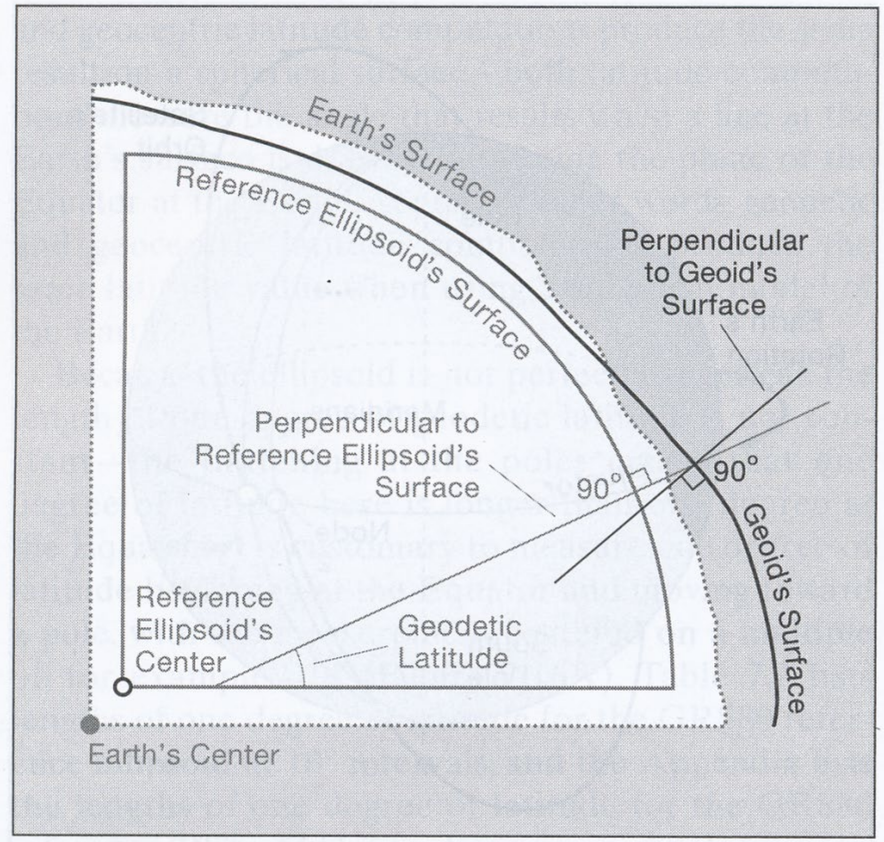
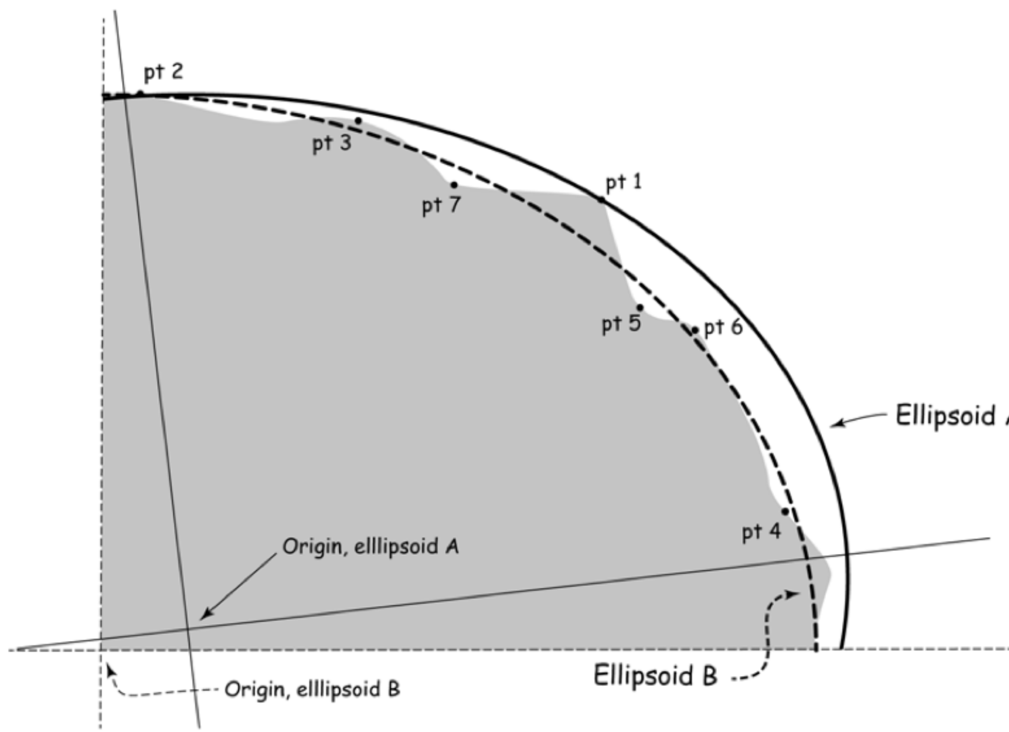


FIGURE 7.18 The relationship among surfaces representing the Earth, a reference ellipsoid, and a geoid. Note that when determining geodetic latitude, a line perpendicular to the reference ellipsoid is not perpendicular to the geoid.

(Source: Slocum et al. 2009)

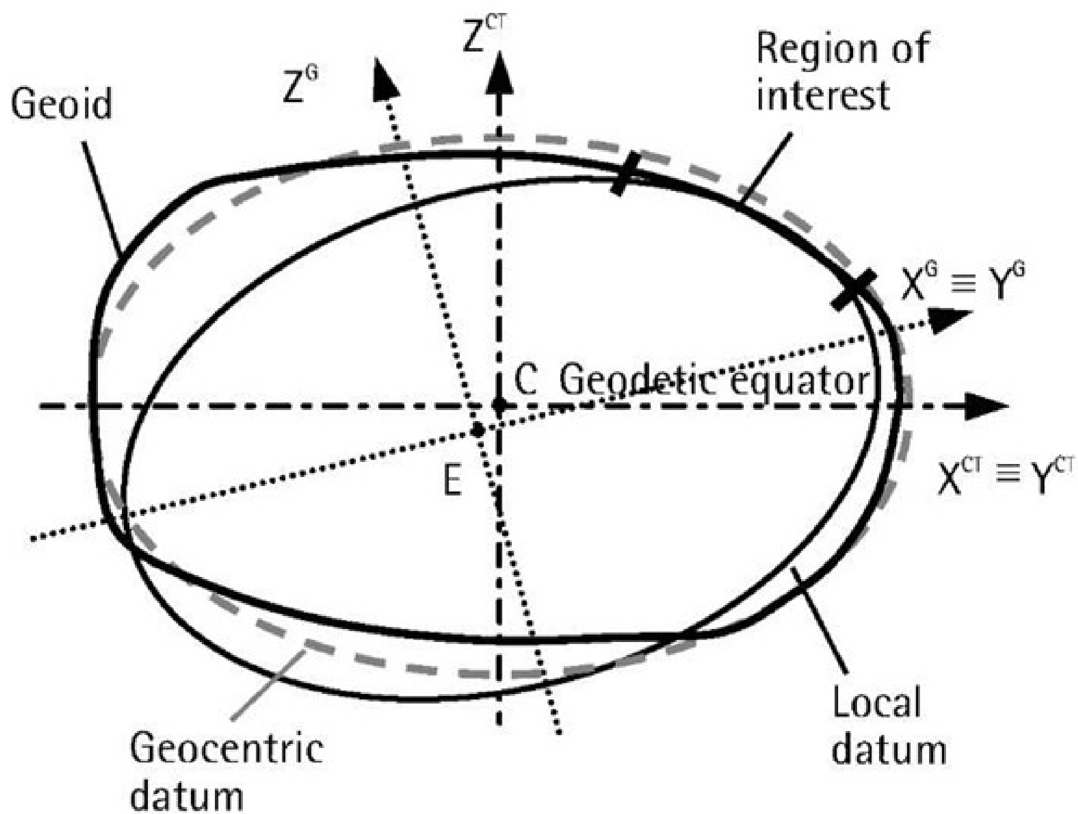
Datum

- A mathematical model of the earth which approximates the shape of the earth, built on top of a spheroid
- Different regions on the earth have different datums (Ellipsoids A and B in the figure)
- Calculations in a consistent and more accurate manner for a specific region
- If comparing GPS coordinates to a chart or map…
  - the map datum in the GPS unit must be set to match the chart for accurate comparison



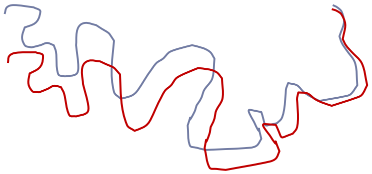
(http://www8.garmin.com/support/faqs/faq.jsp?faq=17; Bolstad, 2012)

Choose datum that better matches to geoid



Why bother?

- Well, a lot of position readings today are done using a GPS and this requires specifying what datum to use.

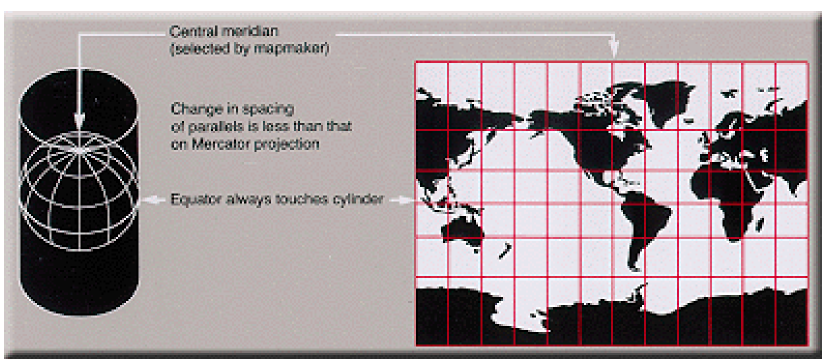


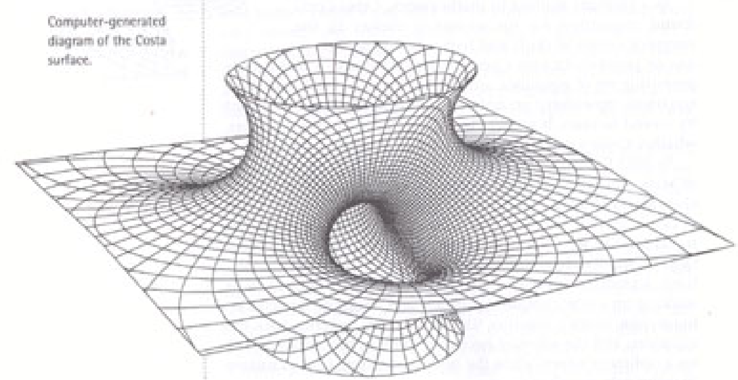
  - (Map's datum = GPS's datum)
  - e.g., scuba diving (this link provides a useful example of applied GPS and earth coordinate knowledge)
- But, for most medium of small-scale thematic mapping we can ignore these details
- 1) Choose a datum, then
  2) choose a projection for your study area to make the map more precise

- (source: http://www.wannadive.net/help/index.html?wdaction=lib.WDPageHelp.gps)

The projection concept

- *Any map projection is the systematic arrangement of the earth's meridians and parallels onto a plane surface (Dent 1999).*
- The basic steps
  - Choose a scale reduction
  - Choose a projection type
    - Direct - developable surfaces (ex. somewhere on Earth)
    - Indirect – purely mathematically defined surfaces





- Ex. A projected map (http://www.answers.com/topic/map-projection) and The Costa surface (http://www.philosophy.umd.edu/Faculty/jhbrown/BtyAdds/)

The scale reduction

- The amount of spatial reduction from real world to the map
- Expressed
  - Numerically
  - Graphically
  - Verbally

Scale 1:700,000 (or 1/700,000)

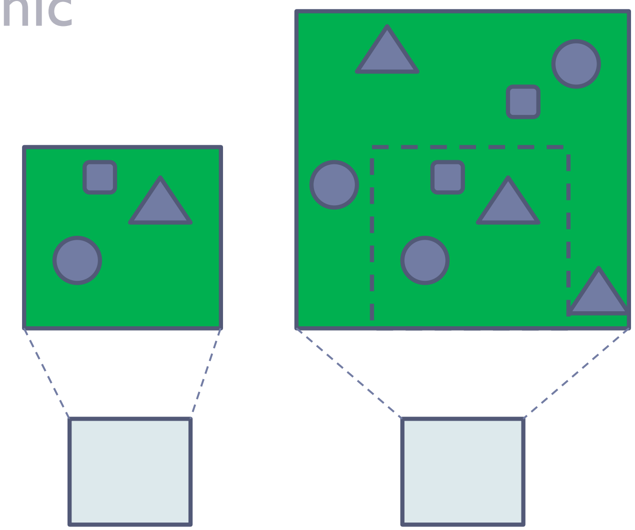
“1mm on the map represents 700,000 mm on the earth”

$$\text{map scale} = \frac{\text{map distance}}{\text{earth distance}}$$

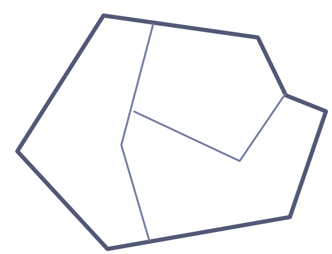
- Generally:
  - Important to use same units when comparing different maps!

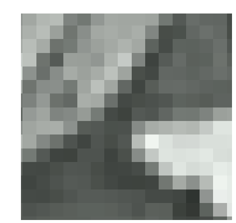
Other statements of scale

- Cartographic
  - Verbal, representative fraction (RF), graphic

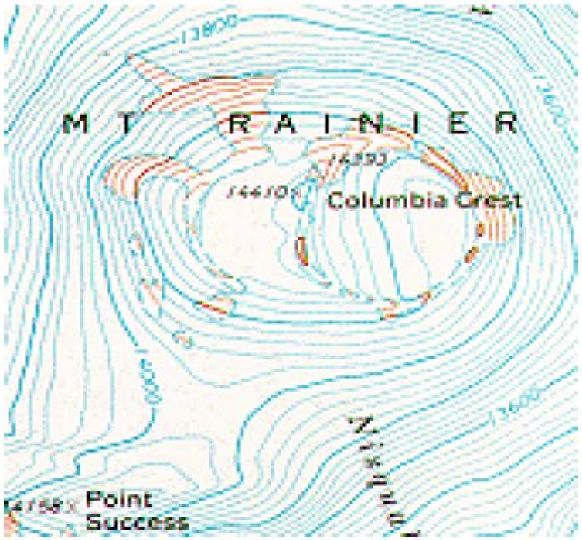


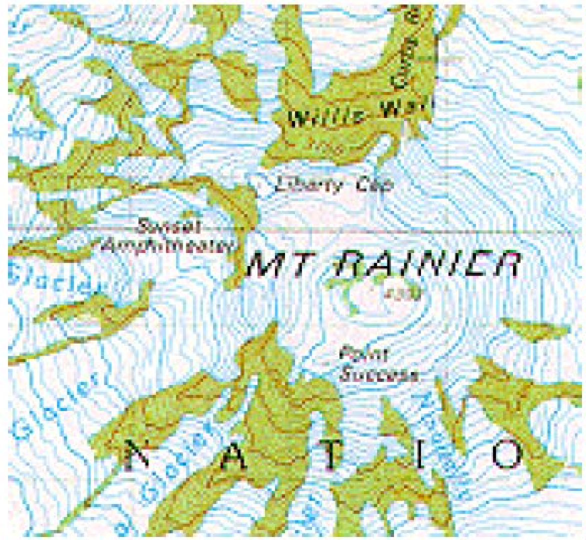
- Geographic
  - "Large" scale, Vs. "small" scale (extents)
- Resolution
  - "Minimum mapping unit"
    - E.g., a census block-group (vector data) or a pixel size (raster data)

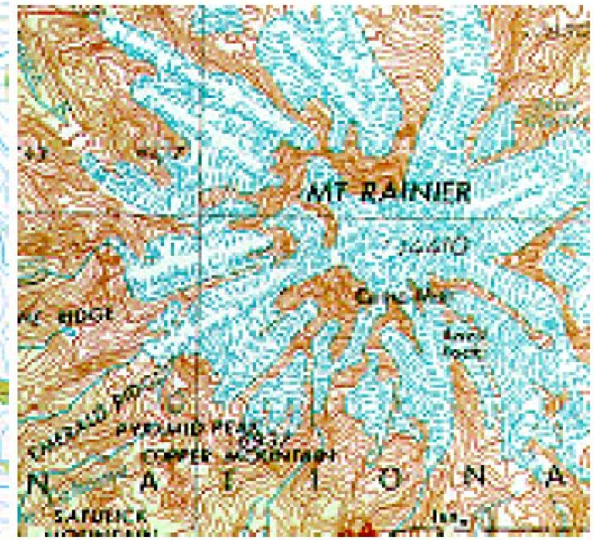




Some common mapping scales







1:24,000 scale,
1 inch represents
2,000 feet

1:100,000 scale,
1 inch represents about
1.6 miles (8,448 feet)

1:250,000 scale,
1 inch represents about
4 miles (21,120 feet)

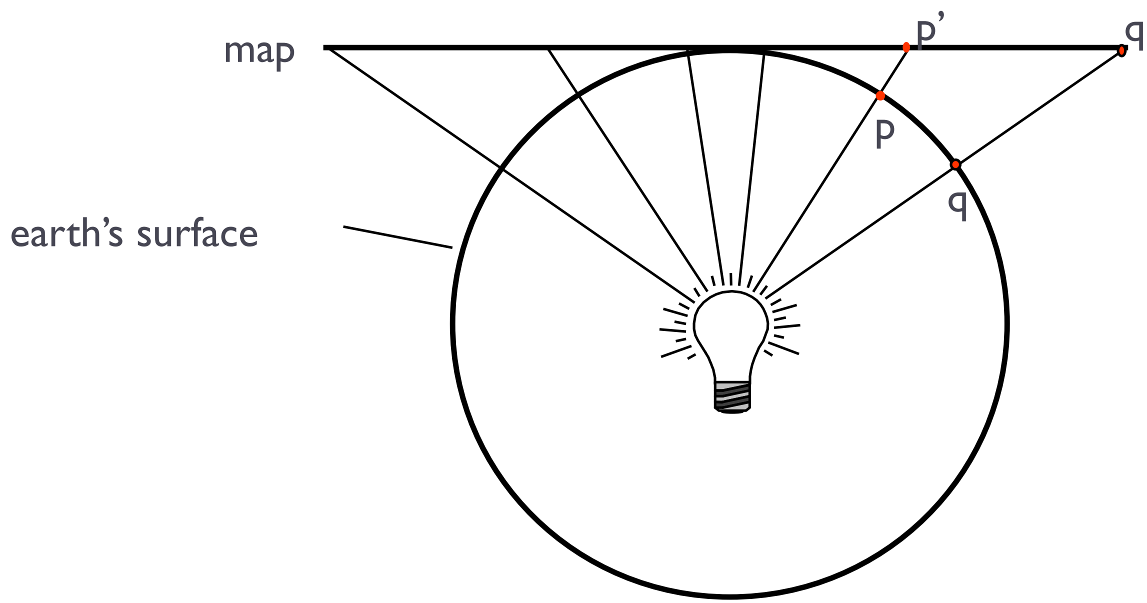
- Q. Using calculator or whatever, answer A, B, and C:

1/24,000 = A 1/100,000 = B 1/250,000 = C

Break!

Choosing a projection

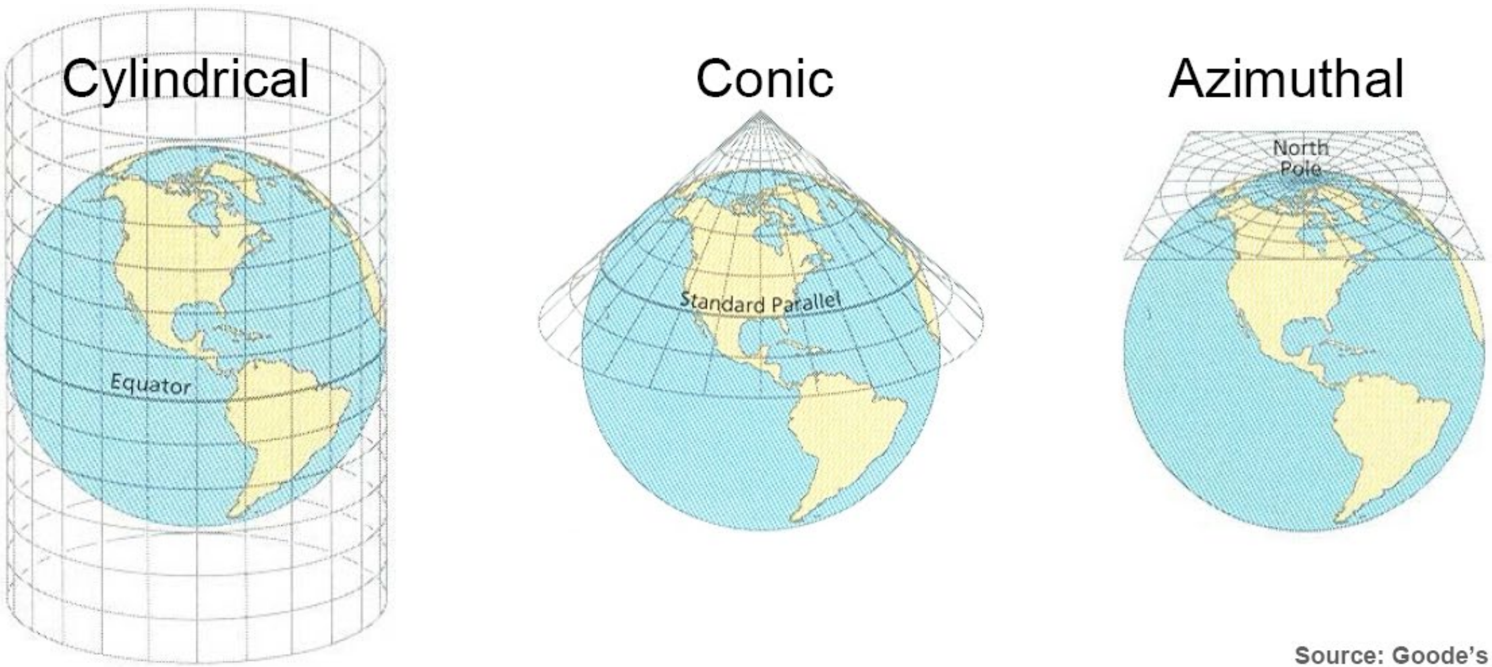
- Checklist
  - Projection properties (Equivalency: area, conformality: angle, equidistance: distance, azimuthality: direction)
  - Deformational patterns across mapped area
  - Projection center
  - Familiarity



Maling, D.H. 1992. Coordinate Systems and Map Projections, 2nd Ed. Pergamon Press. Oxford.

Selecting map projections

- Three basic rules (after Maling, 1992)
  - A country in the tropics asks for a cylindrical projection.
  - A country in the temperate zone asks for a conical projection.
  - A polar area asks for an azimuthal projection.



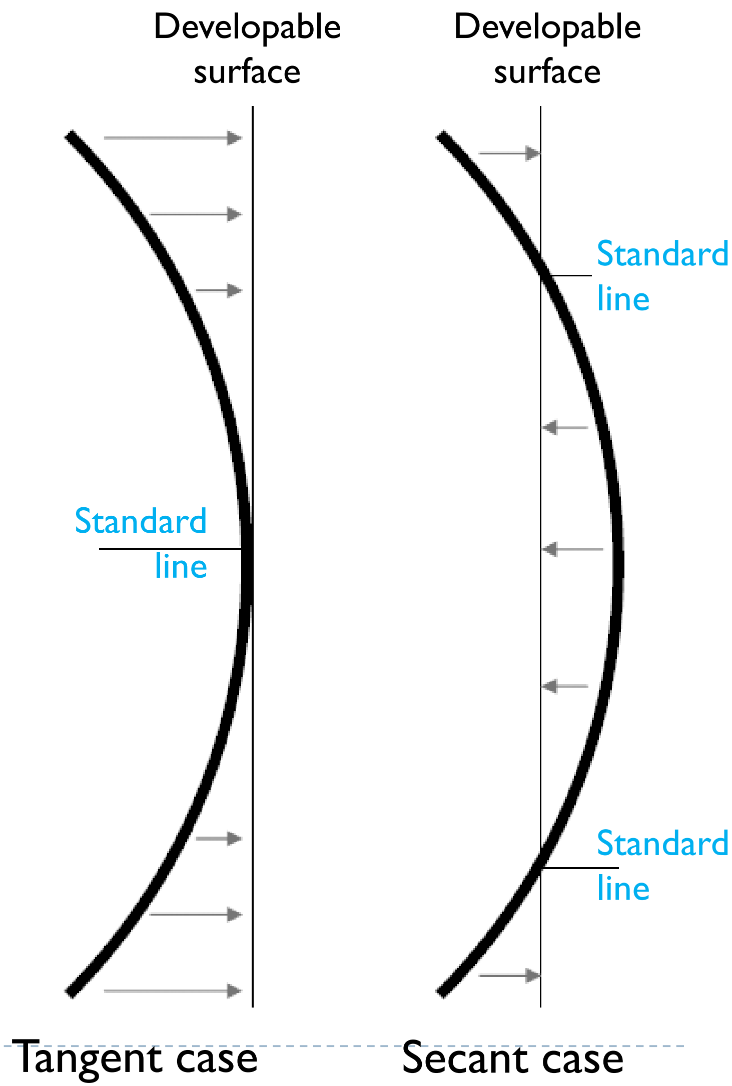
Source: Goode's World Atlas

Projection and distortion

- Each projection creates specific distortions
- Typically we can choose to preserve one or two spatial properties but not all:
  - Areas – *Equivalent proj.*
  - Angles – *Conformal proj.*
  - Distances – *Equidistant proj.*
  - Directions – *Azimuthal proj.*
  - *See Table 9.1 (p.155) on the textbook for details of Named Projection for each Property of projection*

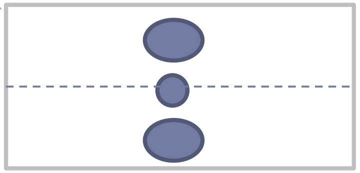
A closer look at distortion

- Distortion increases away from the standard line
  - Scale on reference globe equals to scale on developable surface *only at the standard line(s)!*
  - Q. What does it mean?
  - Q. Scales and amount of distortions are (the same/different) for every location on the map
    - Scale Factor *(next)*
- Ways to mitigate distortion
  - Secant *case (intersect 2 points)*
  - Modify *aspect of projection*



Scale Factor = $\frac{\text{Local scale}}{\text{Principal scale}}$

Distortion increases away from the standard line.
Then how much distortion?



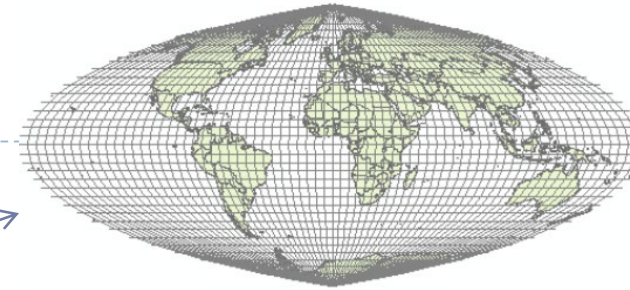
- How to calculate:
  - Step1. Get the *Principal scale* *(=RF, representative fraction)*
    - Conventional constant scales for particular projections measured on standard line(s) or point(s)
      - e.g., 1:250,000, 1:100,000, 1:10,000 …
    - The scale of a reduced or generating globe representing the sphere or spheroid
  - Step2. Calculate the *Local scale* (at the location of interest on the map) *(e.g., 1:239,000)*

$$\textit{Local scale} = \frac{\textit{Map distance}}{\textit{Earth distance}}$$

  - Then calculate… local scale/principal scale
    - If the answer is < 1 = compressed
      If the answer is > 1 = exaggerated
      If the answer is = 1 = no distortion

Scale Factor Example

- Quartic Authalic Projection –
  its Principal Scale is 1:300,000,000
  (Standard line is 0°at the Prime Meridian)



- What is the SF at some point along the 40°N parallel between 0° and 15°?

1. Measure the distance on the map. If you measured with a ruler the distance between 0° and 15°at 40°N parallel = 0.41 cm (map distance)
2. Get true length of 1°longitude at 40°from Appendix A in textbook = 85,393.86 m
3. Multiply by number of degree's (15 x 85,393.86 m = 1,280,907.9 m) (earth distance)
4. Complete the equation: $$\text{Local scale} = \frac{\text{map distance}}{\text{earth distance}}$$
5. 1,280,907.9*m* is 128,090,790*cm* $$\text{Local scale} = \frac{0.41}{128{,}090{,}790} = \frac{1}{312{,}416{,}560}$$
6. $$\text{Scale factor} = \frac{\text{Local scale}}{\text{Principal scale}} = \frac{1\,/\,312{,}416{,}560}{1\,/\,300{,}000{,}000} = \mathbf{0.96}$$ **← exaggerated or compressed ?**

Exercise 1

- What is the scale factor when the map distance is 0.9cm? (still at some point along the 40°N parallel between 0° and 15°)
  - True length of 1°= still 85,393.86 m
  - Earth distance: 15 x 85,393.86 m = 1,280,907.9 m
  - 1,280,907.9*m* is 128,090,790*cm*

$$\textit{Local scale} = \frac{\textit{map distance}}{\textit{earth distance}}$$

$$\textit{Local scale} = \frac{0.9}{128{,}090{,}790} = \frac{1}{142{,}323{,}100}$$

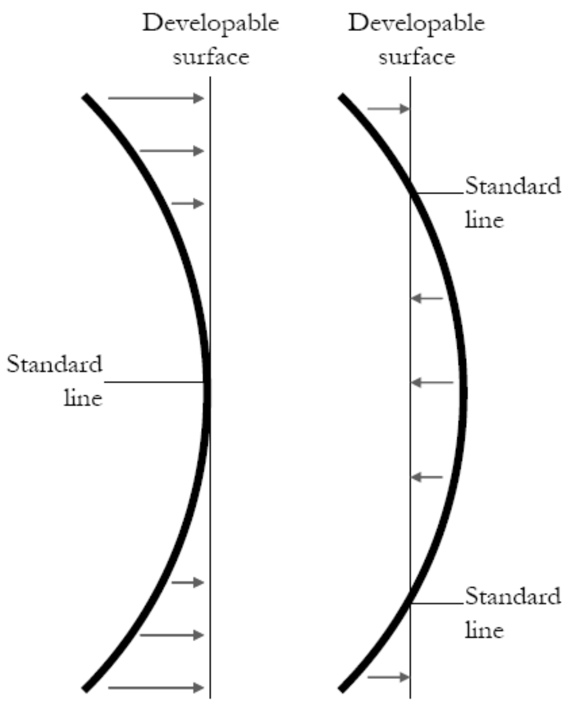
- Scale factor: $\dfrac{\textit{Local scale}}{\textit{Principal scale}} = \dfrac{1/142{,}323{,}100}{1/300{,}000{,}000} = \mathbf{2.11}$ ← **exaggerated or compressed ?**

Exercise 2

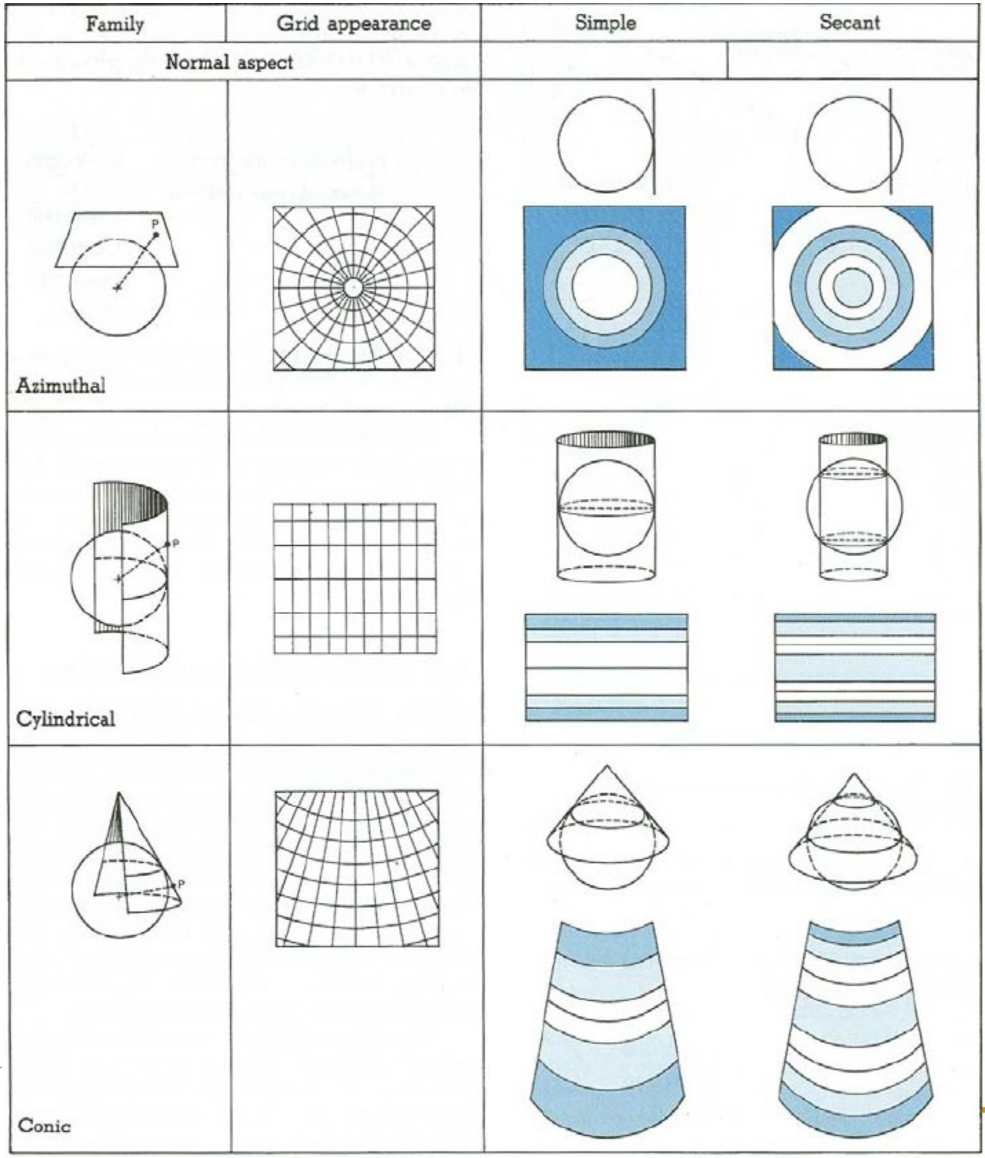
- What is the scale factor when the map distance is 0.3cm? (still at some point along the 40°N parallel between 0° and 15°)

Scale factor varies across a projected map

- Depends on
  - Type of projection
  - Case
  - Aspect



- Tangent case   Secant case



Aspects by latitude

- Equatorial
- Oblique
- Polar

See how shapes and sizes of the lands change

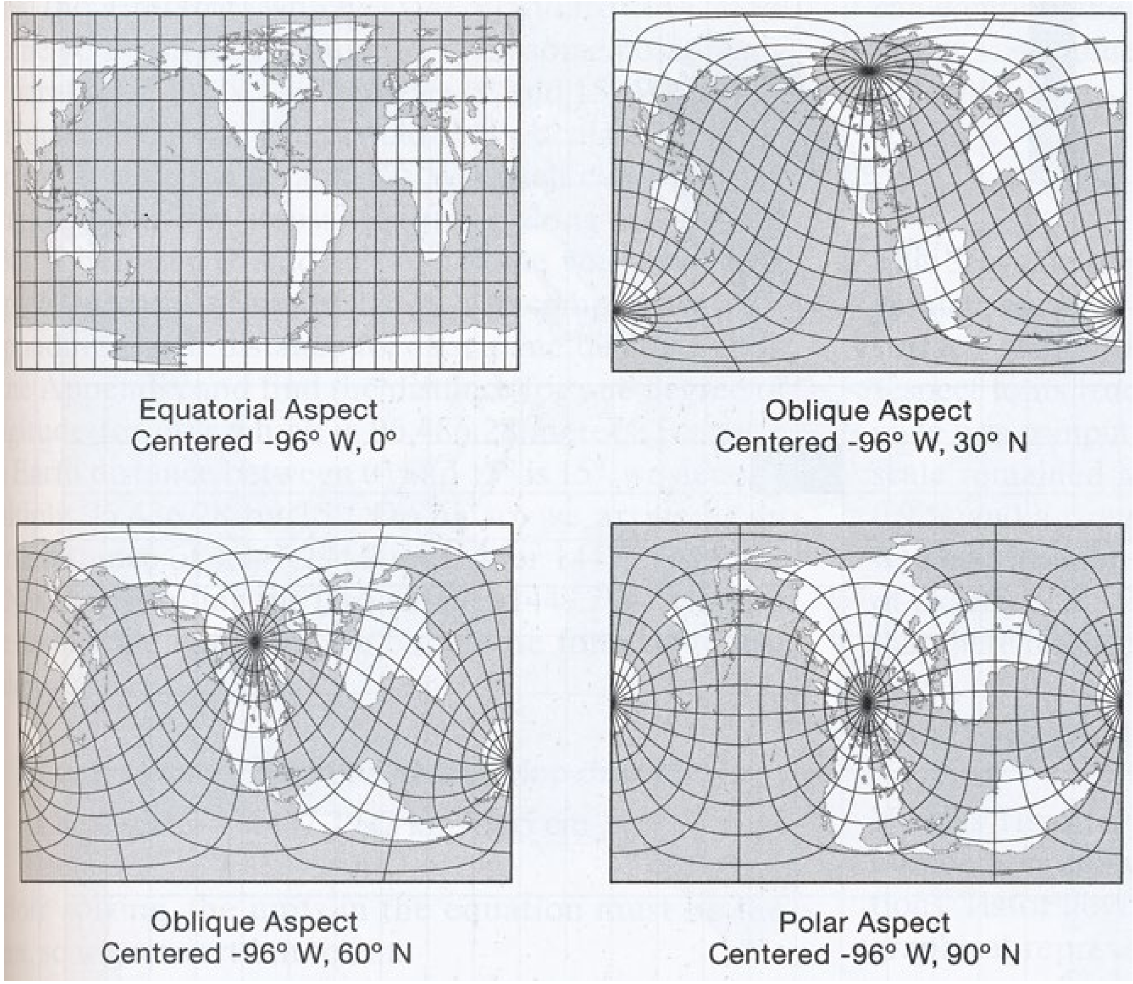
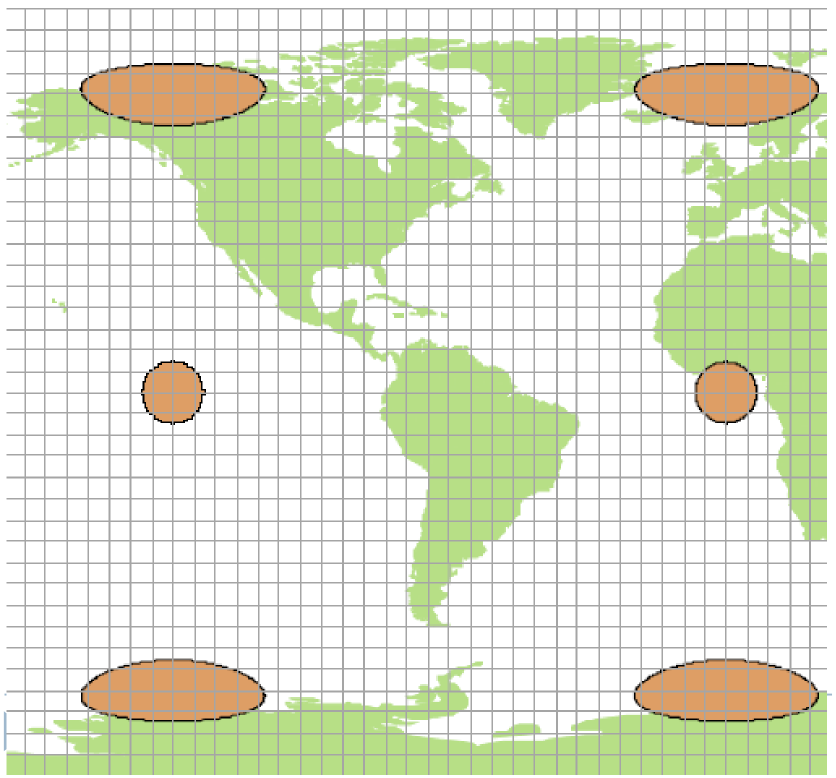
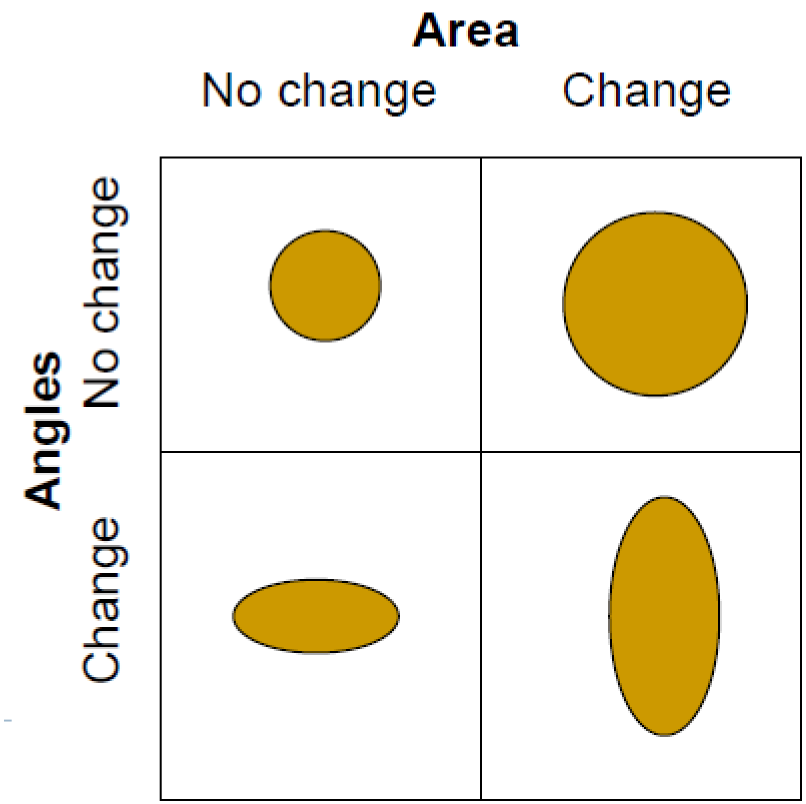


Figure 8.14 (Solcum et al. 2009)

Tissot's indicatrix

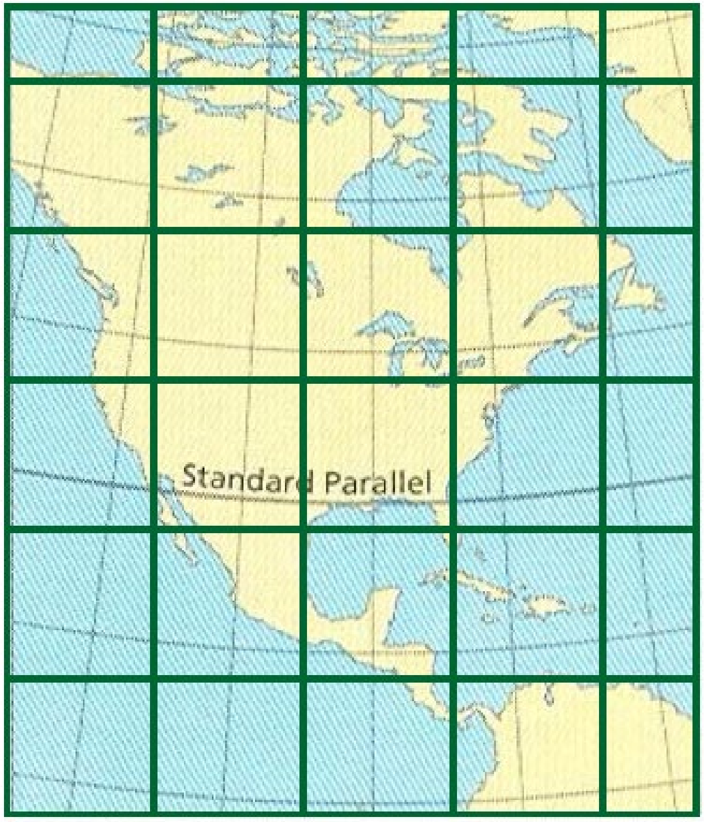
- A way to visually explore and understand distortion of different projections
- A *symbol representing a really small point on the* reference globe with unit radius





Geographic vs. projected coordinates

- Because of projection a geographic coordinate grid will typically not be square-shaped
- This is inconvenient in a flat map context and also in a GIS where digitizers and remote sensing data use square grids
- It also introduces errors in Euclidean measurement



geographic coordinate grid   projected coordinate grid

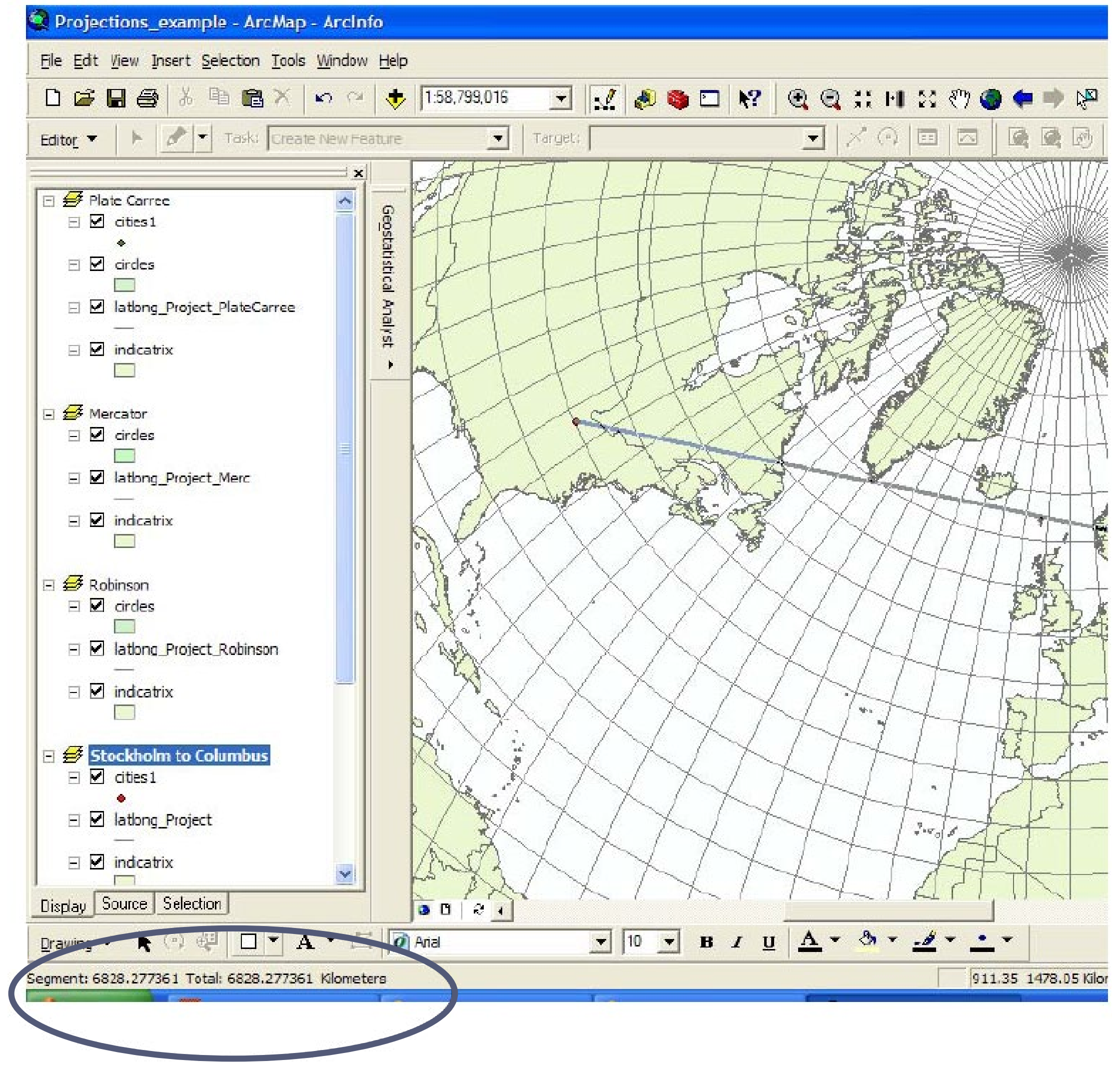
Source: Goode's World Atlas

Choices, choices, choices…

- Snyder's projection selection guidelines
  - World (Table 9.1, p.155)
    - Conformal
    - Equivalent
    - Equidistant
    - Straight loxodromes
    - Compromise
  - Hemisphere (Table 9.2, p.156)
  - Continent, ocean or smaller (Table 9.3, p.158)

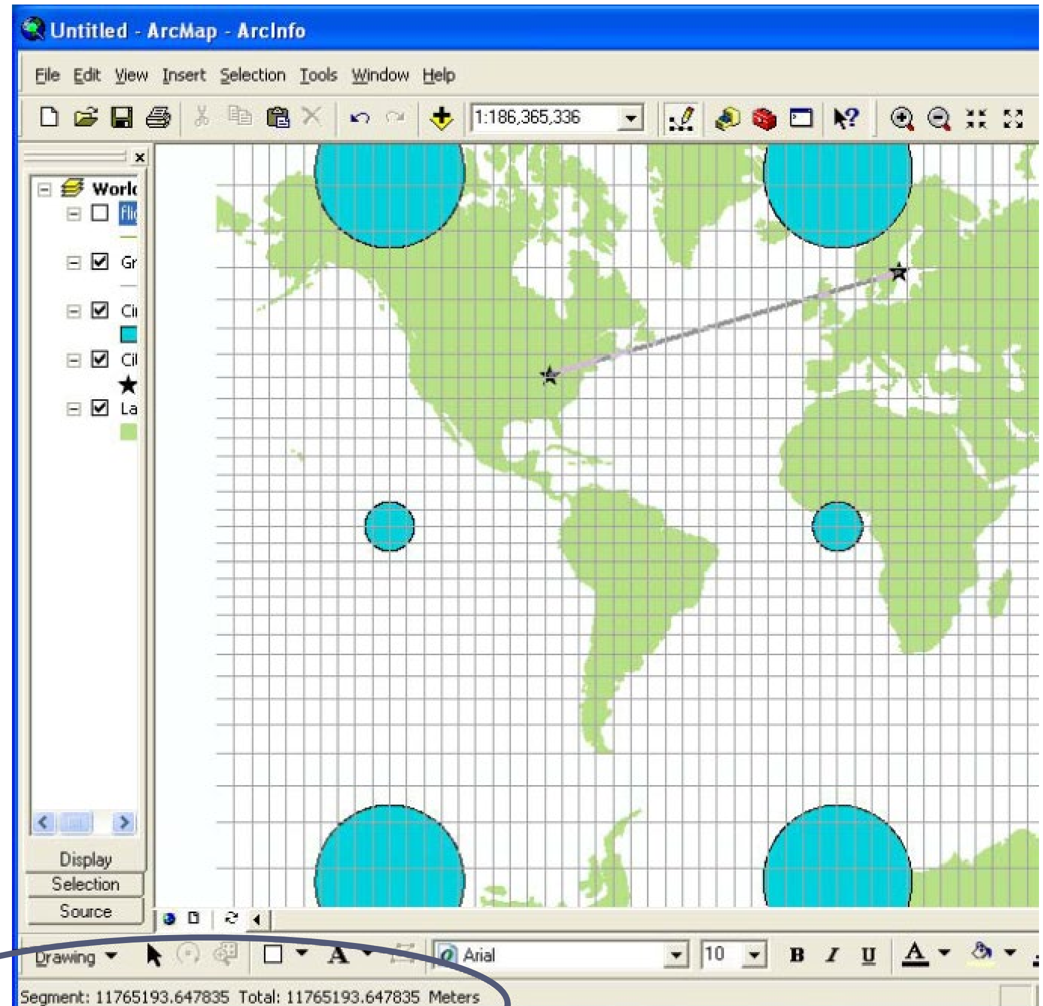
Measurement error example

- Using a geographic grid, distance between two points is calculated along great circles from a central point
  - E.g., 6,828km



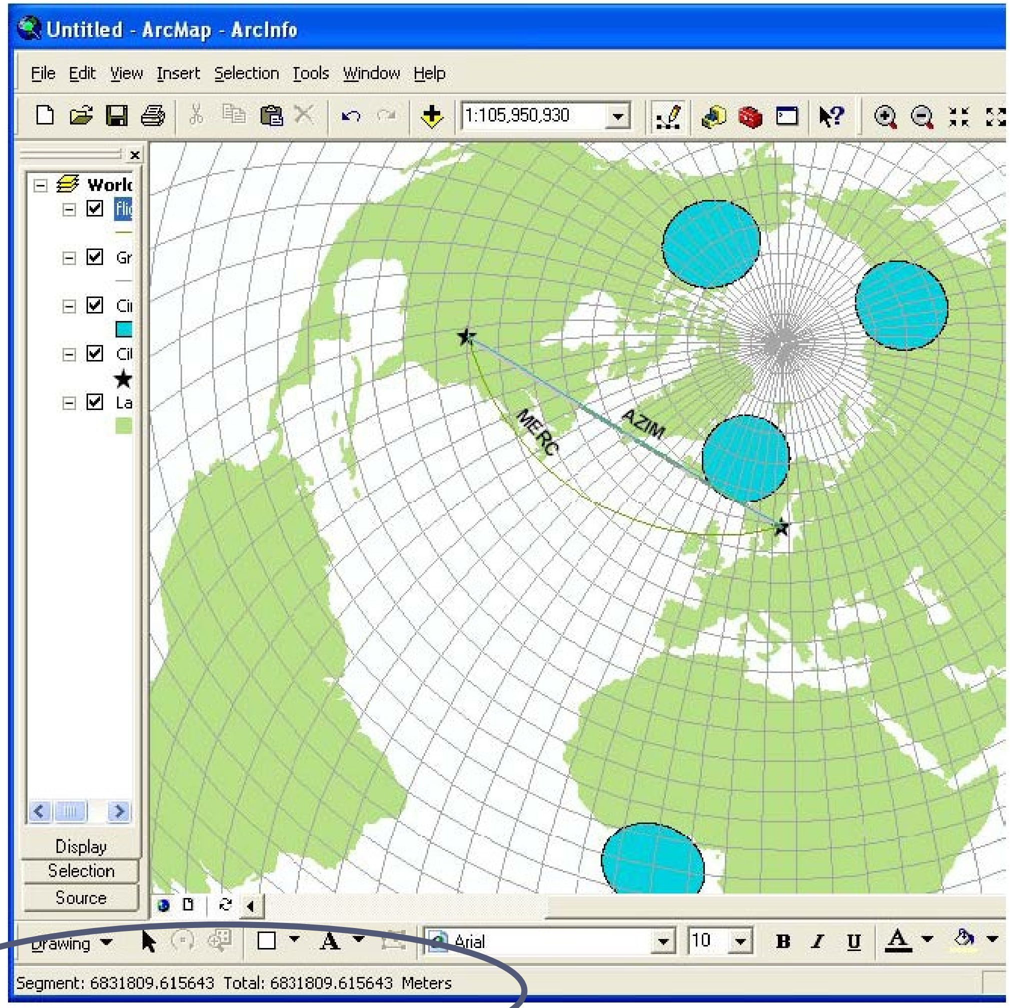
Mercator distance

- Projected data as measured on a map will be distorted
- What really is 6,828km is measured to be about 11,700 km!



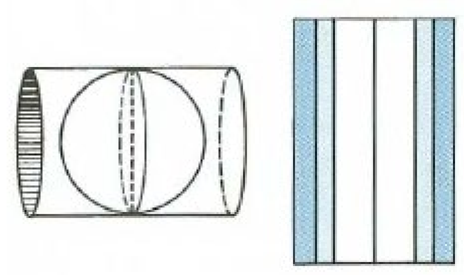
Azimuthal distance

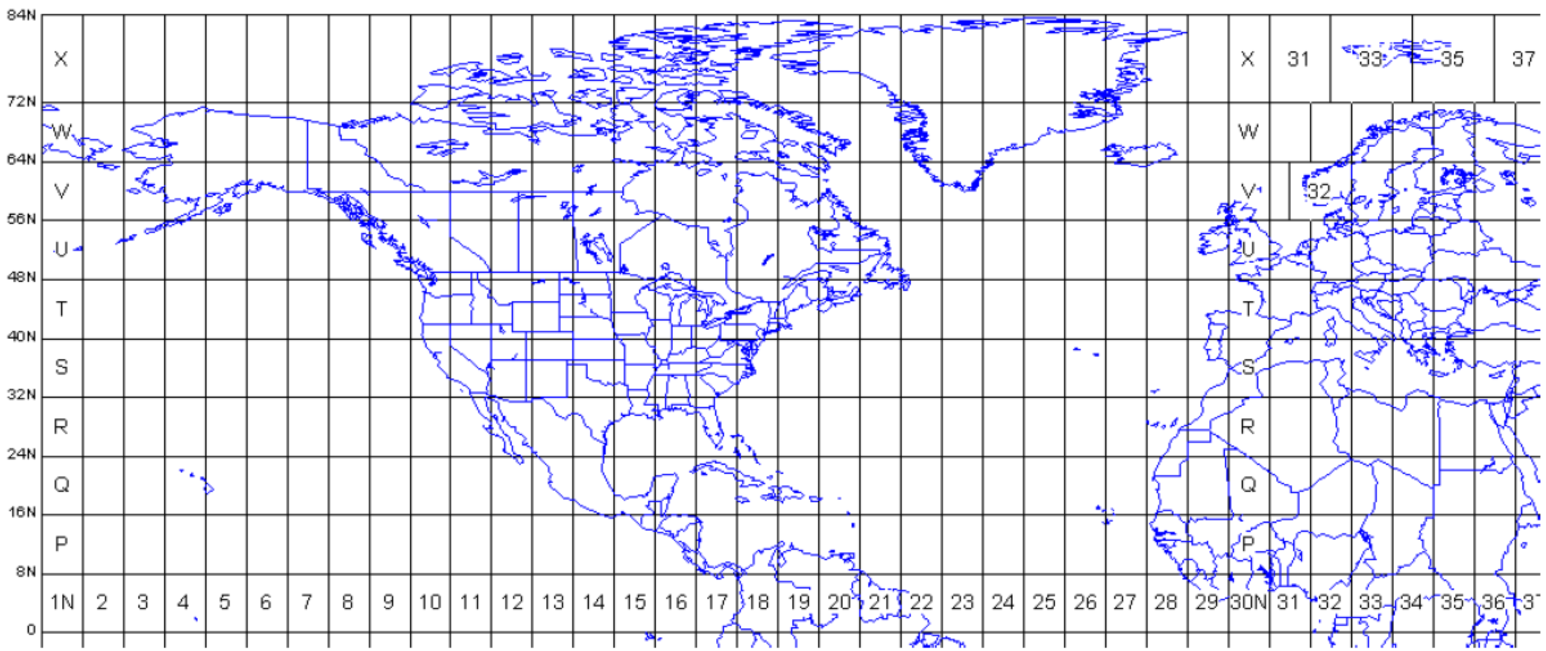
- Equidistant azimuthal projection centered on two different points can be used to measure the correct distance
- What is a straight line in Mercator projection is a curved line (loxodrome) in Azimuthal projection
- What really is 6,828km is measured to be about 6,832 km!



Some common map coordinate systems

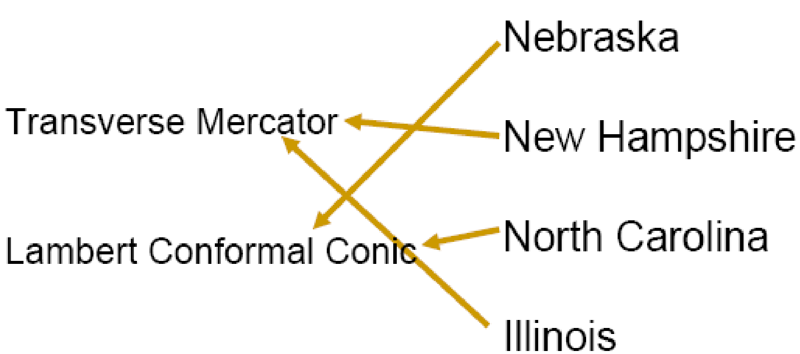
- Universal Transverse Mercator (UTM) grid
  - Specified for 60 x 20 zones (ex. 11N)
  - Measured in meter
  - Distortions within 1 meter





Some common map coordinate systems (cont.)

- State plane coordinate systems (SPC)
  - Each state uses an optimal projection
  - Measured in feet
  - Distortions less than 1 foot
  - False Easting, Northing

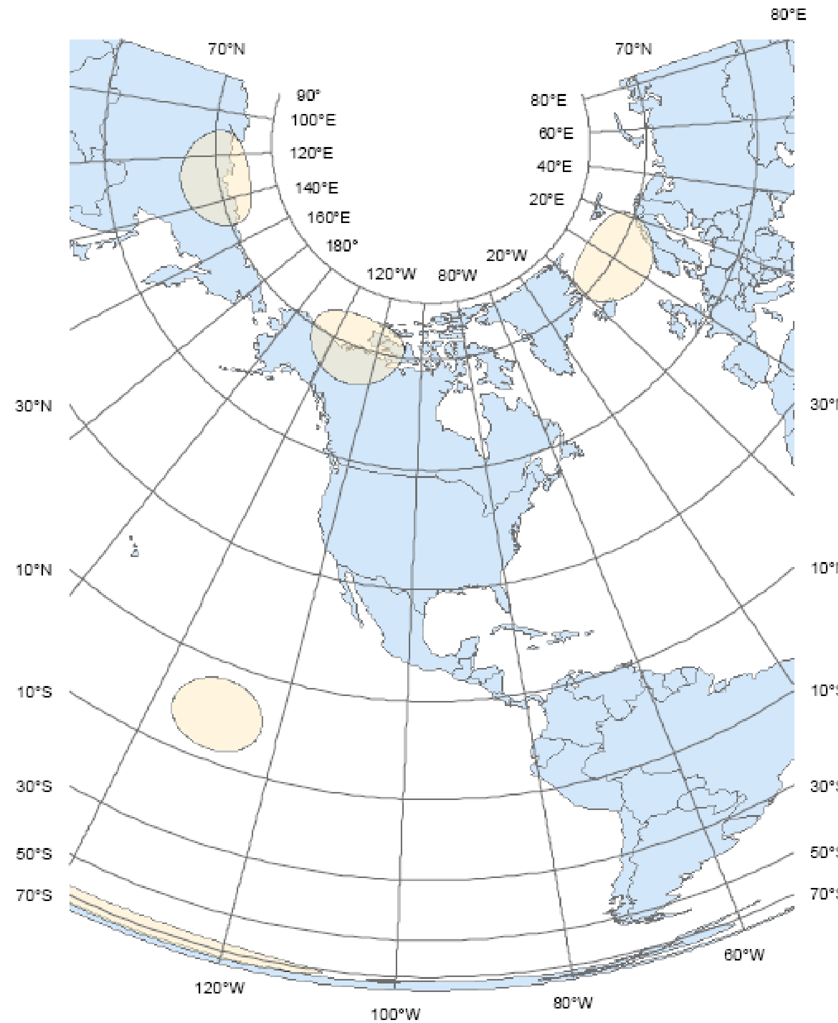


California State has 6 SPCs

Source: http://www.warnercnr.colostate.edu/class_info/nr502/lg3/datums_coordinates/spcs.html
http://www.conservation.ca.gov/cgs/information/geologic_mapping/state_plane

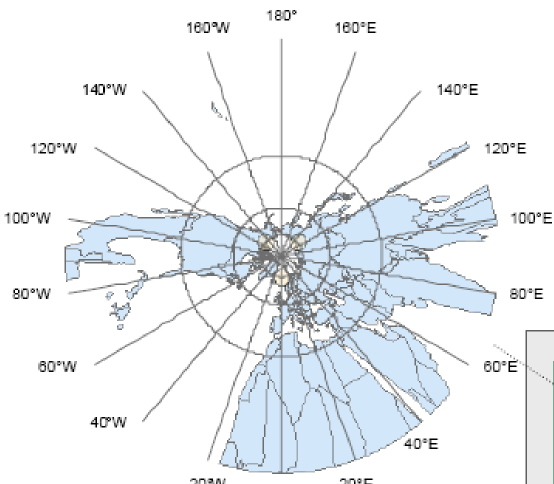
Appendix. More projection examples - Albers Equal Area Conic

- Equivalent – Equal area
- Conic developable surface
- Works very well for mid-latitudes

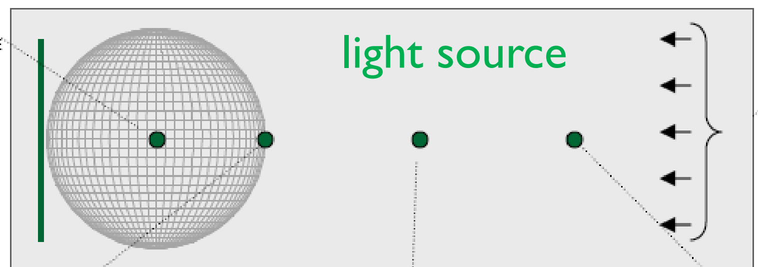


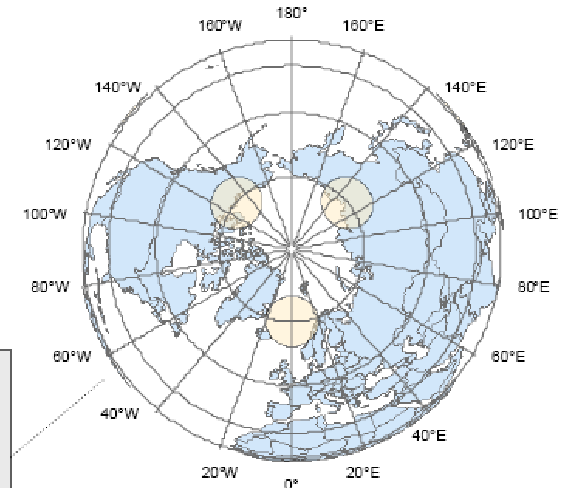
Azimuthal projections

- All have circular distortion pattern suitable for similar shaped areas
  - Antarctica
  - North America

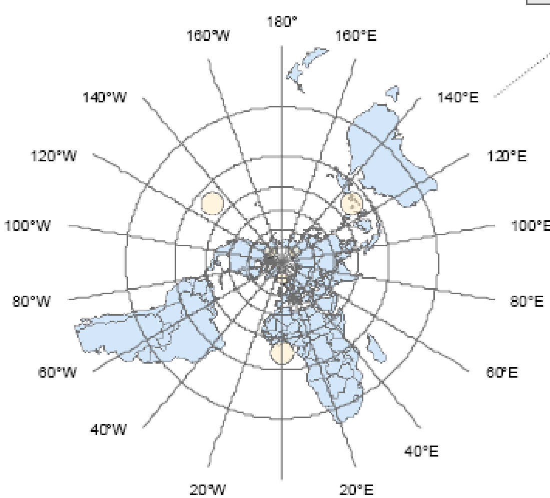


Gnomonic

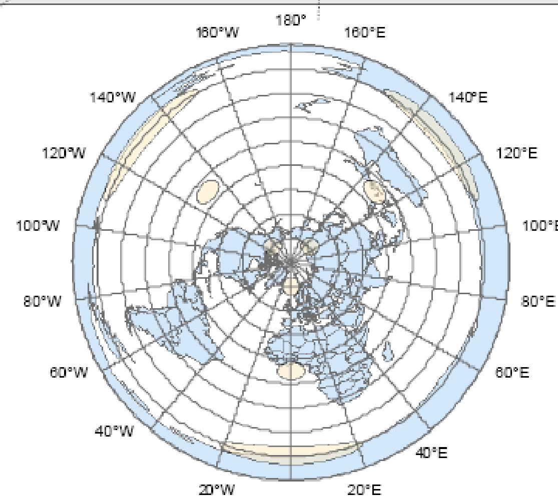




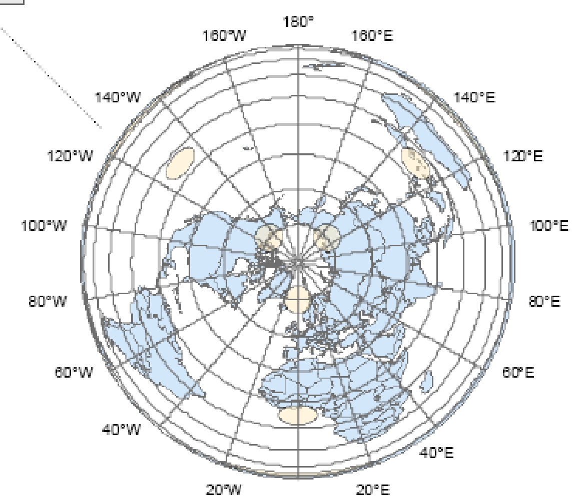
Orthographic



Stereographic

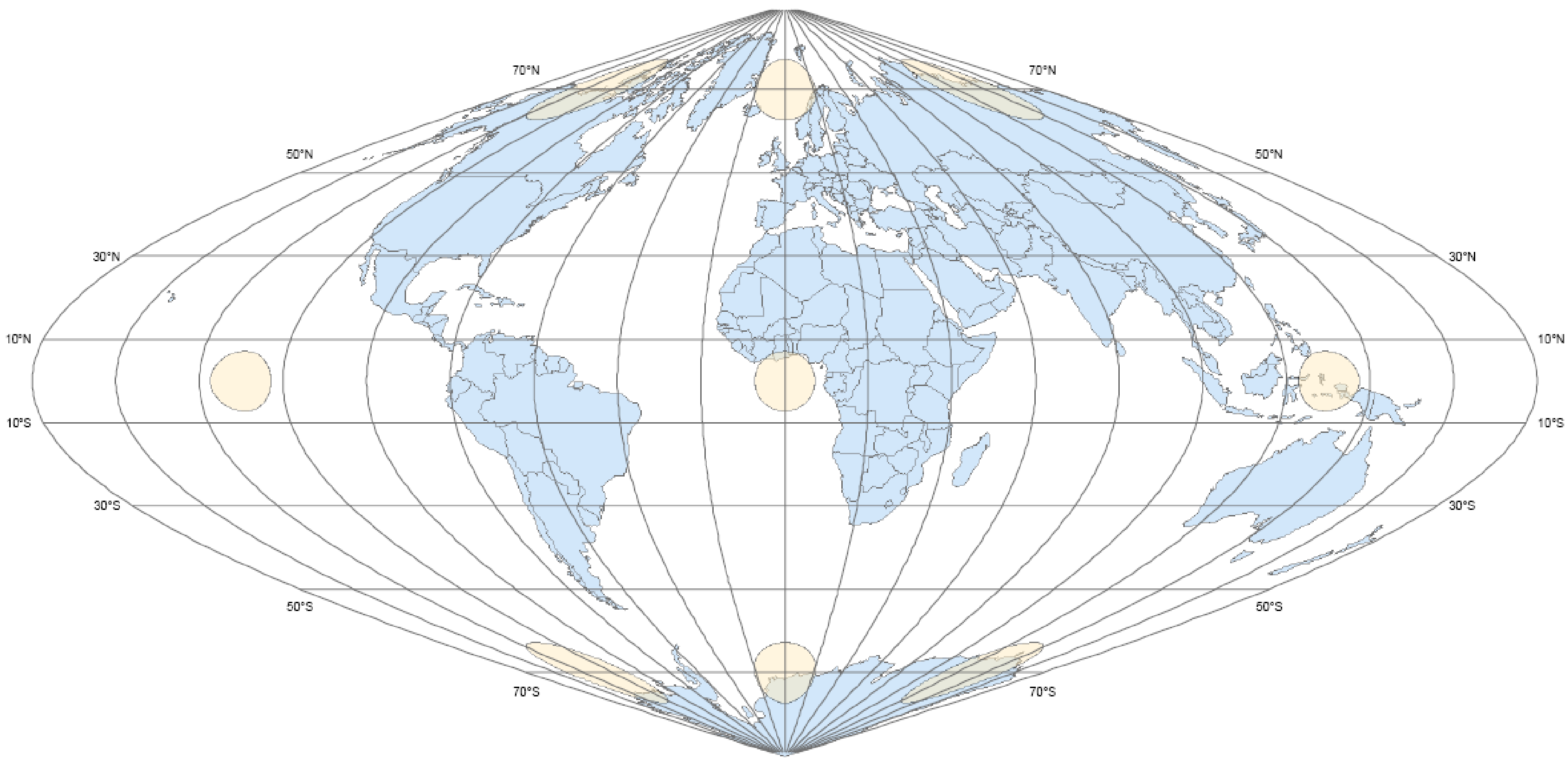


Equidistant

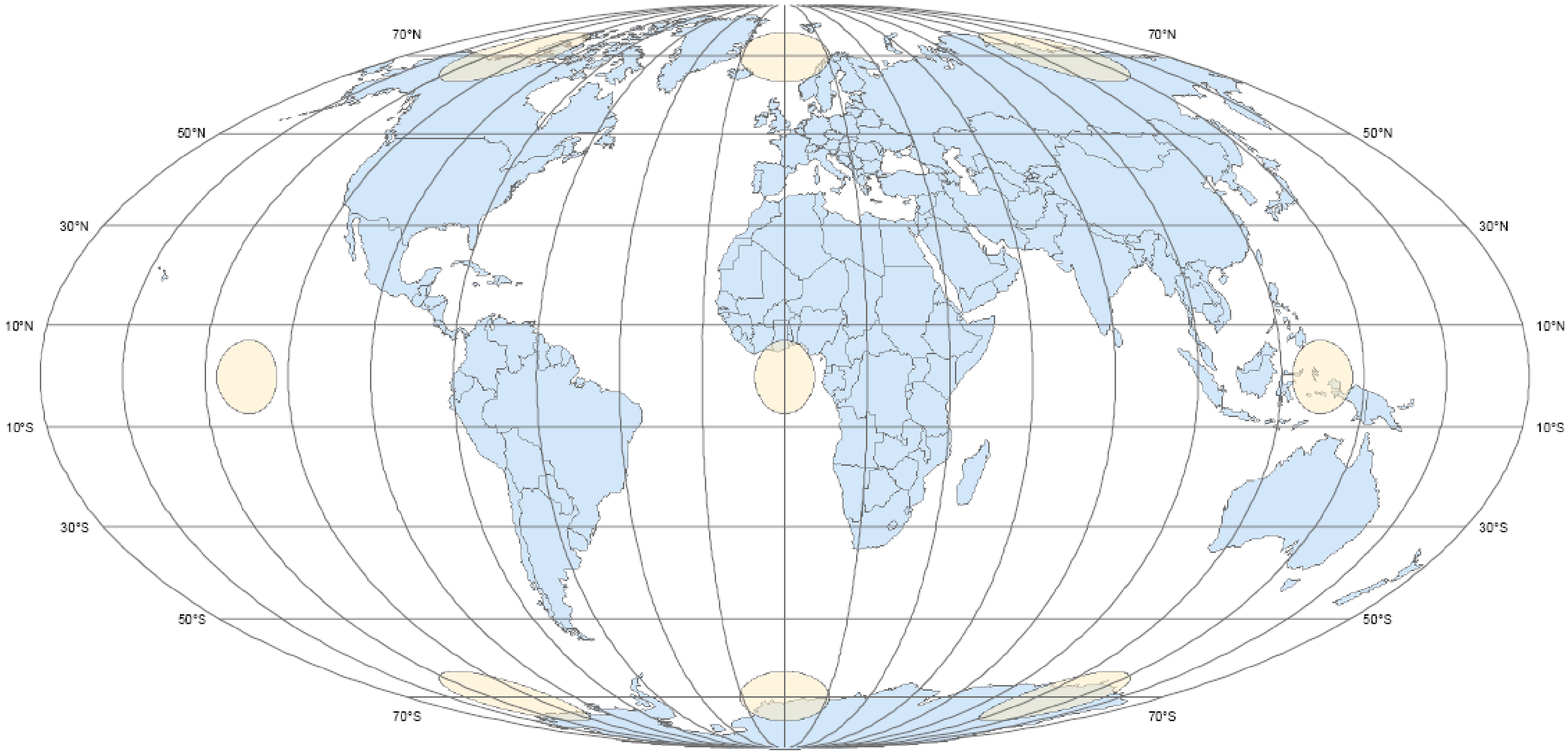


Equivalent

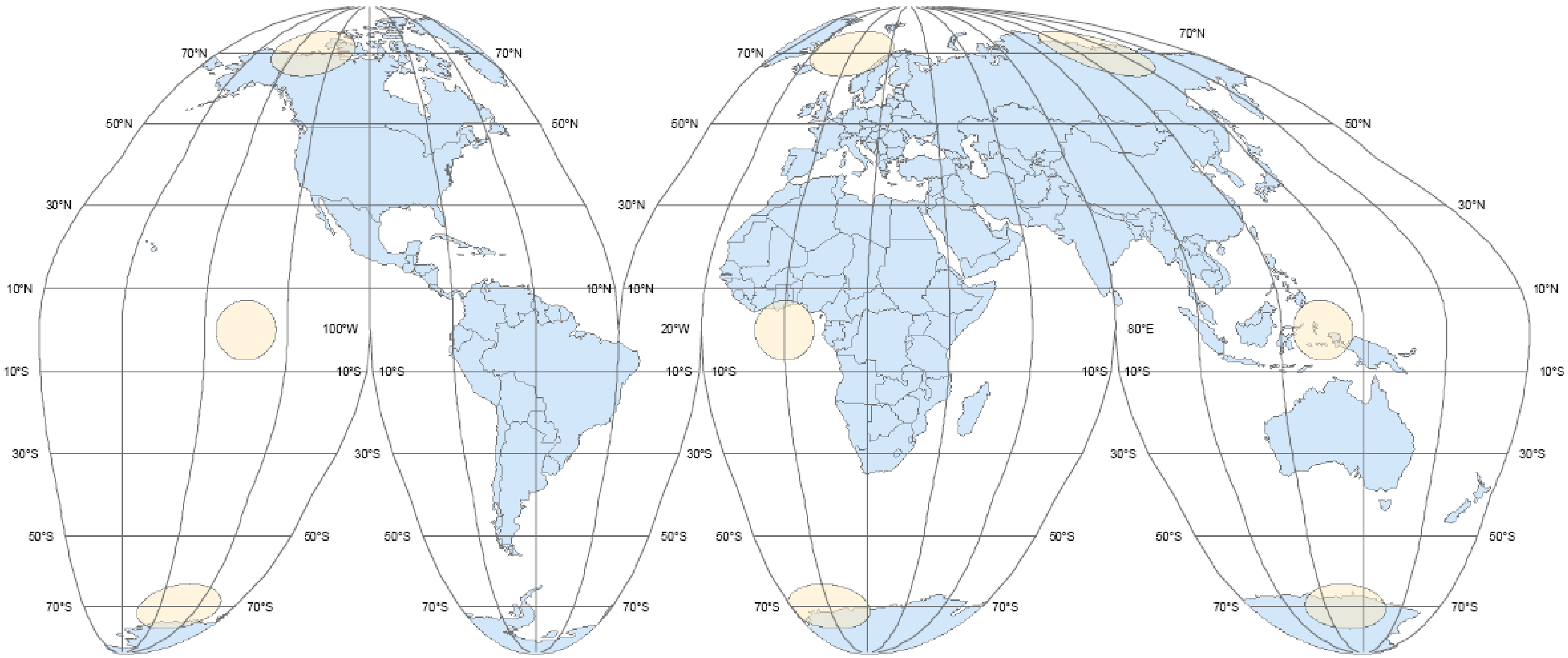
Equal area Projections - Sinusoidal



Equal area Projections - Mollweide

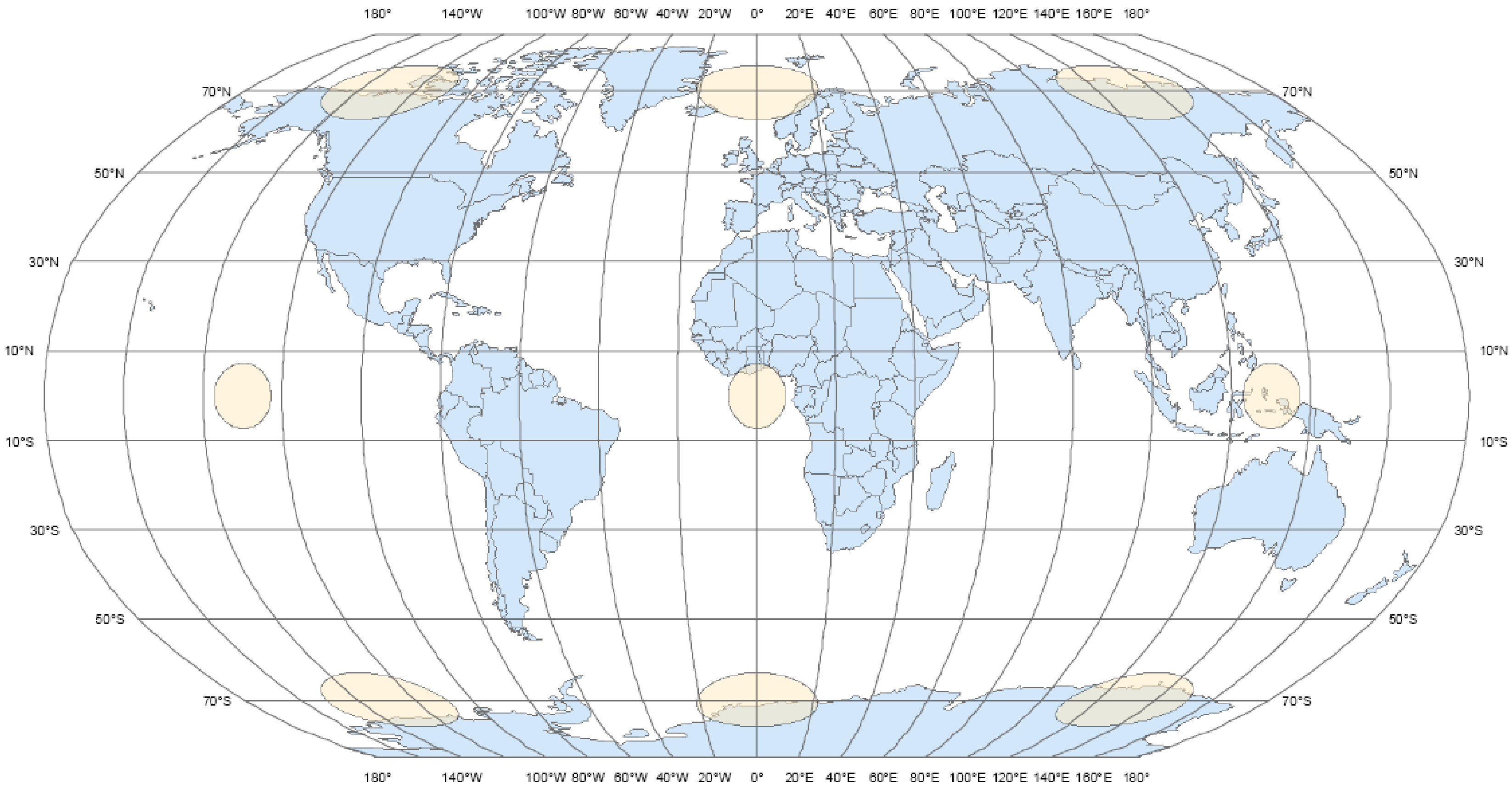


Equal area Projections - Goode’s homolosine



Robinson

- Compromise – minimize distortion (shape, area, angle…)



For next time

- Reading
  - Ch. 5
- Lab1 on Thursday
- Questions…?